Husky Energy **REPORT**

REPORT TITLE

Safety Assessment of South White Rose Expansion Project

SUBMITTED TO

Husky Oil Operations Limited

Husky Energy

235 Water Street, Suite 901

St. John's, NL

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SUBMITTED BY

Atkins

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COMMENTS IF APPLICABLE

Cover sheet for attached Atkins Report – Atkins # - 5033902-RP-015 Rev 1

Signature:	Gavin A. Chisholm	[signature]	
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	Prepared or Reviewed By	Accepted or Approved By	Acceptance or Approval Date

File Code:		HDMS No.:	**003978139**	Report No.:	**SX-HSE-RP-0001**	Version No. No.:	**1**

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ATKINS

Safety Assessment of South White Rose Expansion Project

Report Number: 5033902-RP-015 Rev1

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Issue Date: October 2006

Safety Assessment of South White Rose Expansion Project

A Report Prepared by

ATKINS

on behalf of

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DOCUMENT ISSUE CONTROL SHEET

Husky Oil Operations Ltd

Safety Assessment of South White Rose Expansion Project

Issue	Date	Purpose	Rev. Desc.	Prepared	Checked	Approved
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2	Sep 2006	For Client Comment	0	LD	GC	GC
3	Oct 2006	Final - Incorporating Client Comments	1	LD / GC GC 05-Oct-06	LFB [signature] 05-Oct-06	GC GC 05-Oct-06

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ABBREVIATIONS

BOP	Blowout Preventor
CO	Carbon Monoxide
C-NLOPB	Canada Newfoundland and Labrador Offshore Petroleum Board
DSV	Dive Support Vessel
ESD	Emergency Shutdown
FE	Finite Element
FPSO	Floating Production, Storage and Offtake Vessel
IRPA	Individual Risk Per Annum
MMSCFD	Million Standard Cubic Feet Per Day
MODU	Mobile Offshore Drilling Unit
PLL	Potential Loss of Life
QRA	Quantitative Risk Analysis
ROV	Remotely Operated Vehicle
SDC	South Drill Center
SGH	Southern Glory Hole
SWRX	South White Rose Expansion Project
TEMPSC	Totally Enclosed Motor Propelled Survival Craft
TR	Temporary Refuge
TRIF	Temporary Refuge Impairment Frequency

S1 SUMMARY

Husky Oil Operations Ltd (Husky) is considering the development of the South White Rose Expansion (SWRX) area. This area is located approximately 4km south of the current Southern Glory Hole (SGH) in approximately 120m of water. Within the new glory hole, one new drill centre will be constructed with wells tied back and into the SGH manifolds. The SWRX drill centre will comprise three horizontal production wells and two horizontal water injection wells with expansion capacity for eight wells. The total predicted recoverable oil from SWRX is 24.4 million bbl. As SWRX facilities will be routed to and from the SeaRose FPSO via the SGH, there shall be minimum requirement to make modification to the FPSO and therefore this assessment concentrates primarily on the subsea activities.

As part of the development, Husky is intending to submit a Development Plan Amendment to C-NLOPB. To support this amendment, Husky has requested that Atkins assess the potential impact of the new development on existing White Rose safety studies.

The purpose of this study is to review existing safety studies that were developed for the White Rose project to determine the potential impact of the new SWRX development. The studies which have been identified as requiring review are:

- MODU Blowout Risk Assessment (WR-HSE-RP-0015) [1];
- MODU Dropped Object Analysis (WR-HSE-RP-0028) [2];
- MODU Risk Assessment (WR-HSE-RP-0020) [3].

In addition, this report details the hazards and risks associated with Diving Support Vessel (DSV) operations, as this was not specifically addressed within the studies listed above.

S1.1 Blowout Risk Assessment

A review of the blowout risk assessment for the SWRX project has indicated that there is an increase in the blowout frequency simply as a result of the increased number of well operations being carried out over the period of the SWRX development.

The consequences of a blowout at SWRX were reviewed and considered to be the same as blowouts at the SGH.

S1.2 Dropped Object Risk Assessment

The dropped object study was also reviewed to determine the potential for damaging subsea equipment as a result of SWRX development and installation activities. The assessment concluded that the frequency of damage to subsea equipment was of a similar order to that assessed for the SGH development. The assessment is conservative as there shall be no SWRX equipment subsea whilst the majority of the well drilling operations are taking place.

S1.3 MODU Risk Assessment

The analysis presented here is based upon the use of a semi-submersible MODU for planned development drilling and completion activities. This assessment has identified hazards to which MODU personnel will be exposed during the well operations in the

SWRX project. The analysis has assessed the potential consequences of such hazards and subsequently determined the associated risk to personnel.

The assessment is based on the Global Santa Fe (GSF) Grand Banks as this MODU has performed operations at the White Rose field. Should there be a requirement for a different MODU to perform the SWRX operations then this assessment shall be reviewed and updated to ensure that the specific MODU risk are included.

The assessment has determined that the TR integrity frequency for the MODU whilst conducting SWRX operations is **4.94×10^{-4}** per annum. Whilst this lies below Husky's defined criteria of **1×10^{-3}** per annum for all major accident hazards, subsea blowouts contribute approximately **1.5×10^{-4}** per annum to the total. This exceeds Husky's defined criteria of **1×10^{-4}** per annum for a single major accident hazard. However, it should be remembered that the MODU has been operating in the White Rose field for a number of years and, in combination with the established procedures in place, should therefore mean that the generic, historical blowout frequency used here is likely to be conservative.

The individual risk levels for various MODU worker groups has also been assessed within this study. The maximum risk level has been assessed as being for the Drill Crew, whose IRPA is **6.50×10^{-4}** per annum. Again, this is below Husky's defined criteria of **1×10^{-3}** per annum**.**

S1.3.3 MODU Risk Results Discussion

The risk levels for the MODU carrying out the drilling activities for the South White Rose Expansion Project are predicted to be slightly higher than the previously assessed risks for the MODU operating in the White Rose field during the development phase [3].

The main cause of the increased risks is the higher number of wells to be drilled and completed. Previously, the risks relating to the year with the highest planned drilling activities were included – this was predicted to be 2005, where the equivalent of 4 wells were to be drilled and 7 completed (see Section 3.1.1). The SWRX project involves the drilling and completion of 5 wells in a 10.5 month period – equivalent to 5.9 in a year. The blowout frequency associated with the drilling of wells is higher than that for well completion and therefore the overall risks associated with blowouts has increased.

Overall, although the risks for the SWRX project are higher than those previously calculated for the MODU operating in the White Rose field, the TRIF and the maximum IRPA remain significantly lower than Husky's Target Levels of Safety (TLS) of 1E-03 per annum.

As the design progresses then the risks associated with the operations shall be reviewed and updated as necessary to reflect any changes. Any assumptions made in this assessment shall also be reviewed to ensure that they reflect the latest design for the Project.

S1.4 DSV Risk Assessment

There will be a requirement to use a DSV and a construction vessel for the installation of subseq equipment, i.e. flowlines, manifolds etc. Whilst these vessels will be present at both locations, the DSV risk assessment investigates the risks to personnel on board the DSV whilst it is on-station at the Southern Drill Centre, to allow modifications relating to the SWRX project to be carried out.

The conclusions of the DSV risk assessment are that the TR integrity frequency is within Husky's criteria at **2.69 x10^{-4}** per annum. The highest risk worker category is the Dive Crew, whose IRPA is calculated to be **7.07x10^{-4}** per annum.

These risk figures assume continuous operation throughout a full year. The operations that are to be carried out by the DSV and constructions vessel for the South White Rose Expansion Project are predicted to last for approximately 48 days. The risks for the actual period of operation can therefore be calculated; the hydrocarbon TRIF is predicted to be **3.53x10^{-5}** and the maximum individual risk to be **1.01x10^{-4}**.

S1.5 General Conclusion

The overall risks associated with the MODU are higher for the SWRX project than previously calculated for the MODU operating at the three existing drill centres; this is primarily due to the increased risks associated with blowouts as a result of the additional wells being drilled over the period of one year. However, it should be noted that the hazards associated with operations at SWRX are considered to be the same as those for similar drilling operations elsewhere on the White Rose field.

In all cases, however, the TRIF and IRPA values associated with the South White Rose Expansion Project remain significantly below Husky's Target Levels of Safety (1x10^{-3} per annum).

S1.6 Recommendations

1) As the SWRX Project progresses it is recommended that this safety assessment is updated to reflect any changes that may occur to the design. It is particularly important that assumptions made within this study are reviewed and updated to ensure that the conclusions drawn remain valid.
2) A review of the traffic management procedures at the White Rose field should be undertaken by Husky to ensure that there are sufficient measures in place to protect the SWRX equipment, and any MODU working at the SWRX Glory Hole, from vessels passing through the field.
3) A White Rose specific field traffic survey should be undertaken to provide a better understanding of the vessels that may pass through the field. The results of this study should be used to develop a ship collision assessment that determines the collision risk to the FPSO as well as any MODU that may be operating in the field.
4) Husky should also review in more detail the potential for icebergs to cause damage or scouring of equipment in the SWRX Glory Hole or flowlines. This review should also include the Ice Management procedures to ensure that the SWRX equipment can be protected to a similar level as existing subsea equipment.
5) The project should review the impact on blowdown rates for the SDC production / test and gas lift lines as a result of the inclusion of the SWRX field. Any increase in the blowdown rates and time may affect the time taken to release the riser buoy via the QCDC system in the turret during a controlled disconnect operation;
6) The ESD shut down times for the SWRX facilities should also be reviewed to ensure that the time to close valves at SWRX is optimised and does not prolong the period of packing that may occur at the FPSO after the riser ESD valves have closed in the turret;
7) The BOP dropped object frequency is based on historical, generic records of such incidents. This frequency should be reviewed to ensure that specific

incidents of dropped BOPs at the White Rose field are taken into account and the frequency revised in future revisions of this report if appropriate;

8) The potential for MODU mooring chains to damage the flowlines or umbilicals has previously been assessed by the White Rose project. However, the potential damage that drifting anchors could cause to the flowlines or umbilical has not been assessed and should be reviewed to ensure that the potential frequency of damage is acceptable.

1 INTRODUCTION

Husky Oil Operations Ltd (Husky) is considering the development of the South White Rose Expansion (SWRX) area. This area is located approximately 4km south of the current Southern Glory Hole (SGH) in approximately 120m of water. The development will require a new glory hole to be constructed with facilities for production, gas lift and water injection and the associated flowlines tied back to the existing SGH. The project will involve the drilling of five new wells at the SWRX area and the installation of subsea facilities. In addition, at the SGH, it will be necessary to carry out some modifications to allow the new wells to be tied back to the existing facilities. As SWRX facilities will be routed to and from the SeaRose FPSO via the SGH, there shall be minimum requirement to make modification to the FPSO and therefore this assessment concentrates primarily on the subsea activities. However, the addition of the SWRX well fluids to the Sothern Drill Center (SDC) flowlines may increase the inventory that could be released at the FPSO, and this has been reviewed within this assessment.

As part of the development, Husky is intending to submit a Development Plan Amendment to C-NLOPB. To support this amendment, Husky has requested that Atkins assess the potential impact of the new development on existing White Rose safety studies. This report has been prepared to assist in the Development Plan Amendment application and reflects the current stage of the SWRX design. It is the intention for this study to be updated and reviewed as the design progresses.

1.1 Scope of Work

The purpose of this study is to review existing safety studies that were developed for the White Rose project to determine the potential impact of the new SWRX development. The safety studies which have been identified as requiring review are:

- MODU Blowout Risk Assessment (WR-HSE-RP-0015) [1] – Reviewed in Section 3;
- MODU Dropped Object Analysis (WR-HSE-RP-0028) [2] – Reviewed in Section 4;
- MODU Risk Assessment (WR-HSE-RP-0020) [3] – Reviewed in Section 5.

In addition, section 5.4.1 of this report details the hazards and risks associated with Diving Support Vessel (DSV) operations, as this was not specifically addressed within the studies listed above.

1.2 Report Structure

Section 2 of the report gives details of the South White Rose Expansion Project, including diagrams representing the new equipment layouts.

The changes to the frequency of blowouts and impairment from dropped objects have been identified within sections 3 and 4 and the revised frequencies are carried into sections 5 and 6 to establish the subsequent change in risk levels. Any direct changes to the Risk Assessments are also discussed in sections 5 and 6.

Section 7 assesses the potential impact that the additional inventory in the SGH flowlines may have on hydrocarbon releases that occur back at the FPSO.

2 SOUTH WHITE ROSE EXPANSION (SWRX) PROJECT

The South White Rose Extension (SWRX) area is being considered for development as shown in Figure 2-1. This area is located approximately 4 km south of the current Southern Glory Hole (SGH), in approximately 120 m of water. Within the new glory hole, one new drill centre will be constructed with wells tied back and into the SGH manifolds. The SWRX drill centre will comprise three horizontal production wells and two horizontal water injection wells with expansion capacity for eight wells. The total predicted recoverable oil from SWRX is 24.4 million bbl.

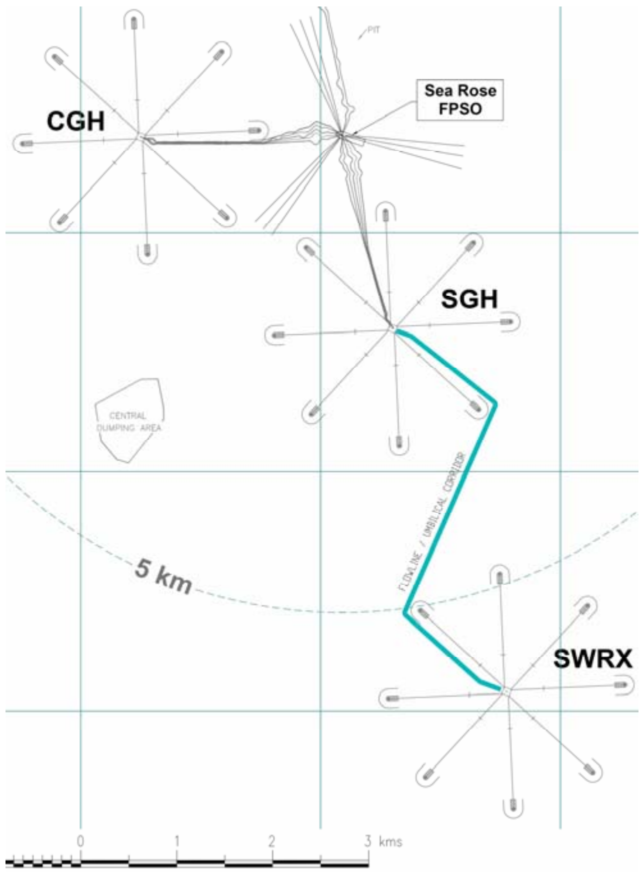

Figure 2-1: SWRX Tieback to the SGH

2.1.1 Subsea Equipment

The subsea facilities at SWRX will include all equipment necessary for the safe and efficient operation and control of the subsea wells and transportation of production and injection fluids between the wells and the SGH. No changes to existing flowlines, risers or umbilicals are anticipated. However, the SWRX development will require modifications of the Southern Drill Centre (SDC) to extend flowlines and controls, as shown in Figure 2-2. Procedures for installation of subsea facilities and subsequent operations for SWRX are anticipated to be the same as those currently employed for the existing White Rose Development.

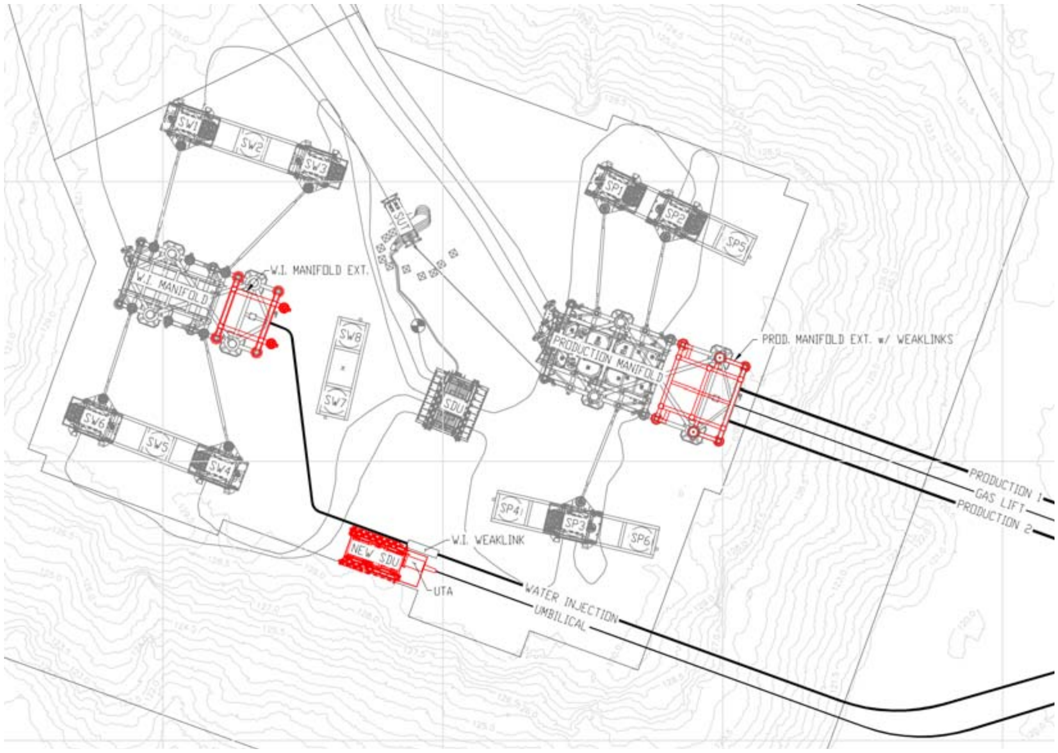

Figure 2-2: SDC Modifications to Support the SWRX Tie-back (New Equipment shown in Red)

2.1.2 SWRX Glory Hole Construction

The glory hole needed to support establishment of the drill centre will be excavated to a maximum of 9-11m below existing seabed level with a maximum “floor” dimension of 70m by 70m and graded sloped sides as required for stability and the flowline ramps. The greater dimensions of the glory hole result from lessons learned during the original White Rose Development. Specifically:

- Increased depth will allow equipment to be installed on purpose made blocks to decrease exposure of wellheads and associated equipment to irregularities in excavation and sedimentation in the bottom of the glory hole;
- A larger size will facilitate unimpeded movement of ROVs, easier equipment installation, and to allow for possible installation of a universal subsea tree structure currently being assessed; and
- Graded slope ramps will facilitate placement of flow lines and may enhance removal or movement of sediment out of the glory hole through increased current flow.

The proposed glory hole layout for SWRX is indicated in Figure 2.3.

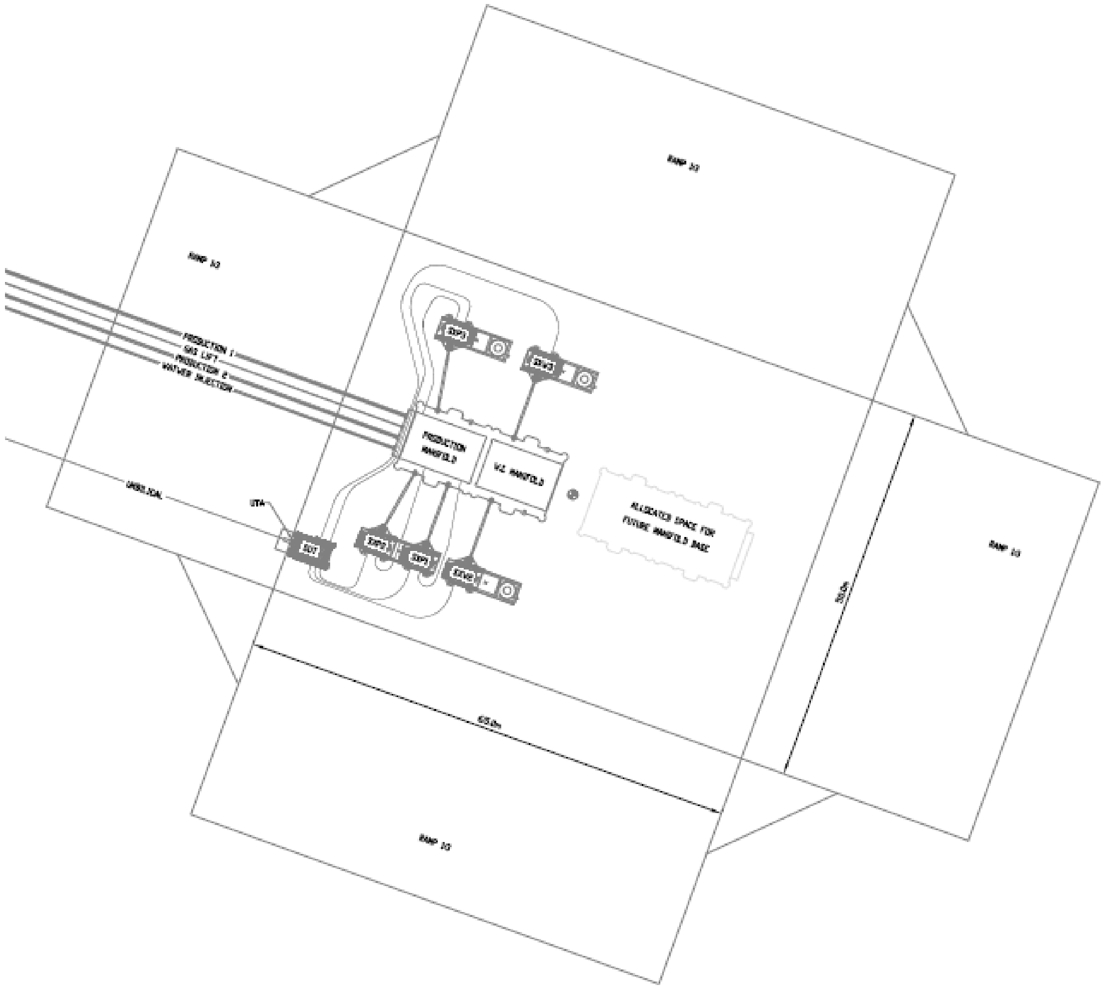

Figure 2-3 Proposed SWRX Glory Hole Layout

3 BLOWOUT ASSESSMENT

The blowout assessment [1] that was conducted for the White Rose project established the consequences and risks associated with the various types of blowouts that could affect the MODU and the personnel on board during drilling and well intervention activities.

In order to achieve this, a number of factors were taken into consideration. These included:

- Type and frequency of well operations (drilling, completion etc.);
- Probability of blowout for each type of well operation;
- Location of blowout (drillfloor, subsea etc);
- Size of blowout (through the drillstring, annulus, unrestricted etc);
- Ignition probability;
- Time to ignition (immediate or delayed).

The location of the blowout, either on the drillfloor, subsea etc, size and ignition probability are considered to be similar for drilling at SWRX as they are elsewhere on the White Rose field. A blowout occurring during the drilling of the SWRX wells will have the same consequences as previously identified; however, the frequency of such an event occurring may change as the number of wells being drilled may be different. The frequency and consequences of blowouts during the development of SWRX are assessed next.

3.1 Well Operations

Well operations under consideration during this evaluation of the risk from blowout for the SWRX project are:

- development drilling from the MODU;
- well completion.

Blowout frequency data for each well operation considered, and quoted in Table 3-1 below, has been based upon data contained in the Scandpower Model for Blowout Risk Prediction [4]. This data is based on historic data from the North Sea and US Gulf of Mexico. Account has been taken of the general downward trend in blowout probability in recent years due to advances in both technology and safety management systems. For the purposes of this assessment, these blowout frequencies are assumed to apply to the drilling and completion of both the production and water injection wells.

Well Operation		Base Blowout Per Operation
Development Drilling from the MODU	Shallow Gas	1.60×10^{-3}
	Reservoir Drilling	1.12×10^{-3}
Well Completion		9.20×10^{-4}

Table 3-1: Summary of the Base Blowout Frequency Data for Each Well Operation

3.1.1 Development Drilling from the MODU

During development drilling, two elements of blowout risk must be considered. These are:

- blowout involving shallow gas;
- blowout from the deep reservoir (hereafter referred to as reservoir blowout).

It is necessary to consider these events separately as they differ both in terms of frequency of occurrence and hazard potential.

3.1.2 Well Completion

Completion of a well is carried out when a development well has been drilled successfully and is required to be brought into production or for injection of gas or water. The completion operation is defined as any installation of production tubing, packers and other equipment as well as perforation and stimulation in production and injection wells.

3.2 Blowout Frequency

In the assessment of blowout risks conducted for the MODU during the development of the White Rose field [1], the worst case drilling year (according to the predicted drilling schedule) was assumed to be 2005, where 6 wells would be drilled and 7 wells completed. Table 3-2 shows the blowout frequencies that were therefore included in the existing MODU Blowout Risk assessment.

Year 2005	**Deep Reservoir**		
Blowout Type	*Drillpipe*	*Annulus*	*Unconfined*
Drillfloor	4.37E-03	2.62E-03	5.46E-04
Subsea	3.39E-03	-	-
	Shallow Gas		
Blowout Type	*Drillpipe*	*Annulus*	*Unconfined*
Drillfloor	-	-	-
Subsea	-	-	6.40E-03

Table 3-2: Blowout Frequency Results from Previous Study

It should be noted that of the six wells that it was assumed would be drilled in 2005, two were new wells, two were top hole section only and two were reservoir section only. In terms of blowout frequency, this is effectively the same as four new wells being drilled (top hole and reservoir combined).

Information provided by the SWRX project suggests that 5 wells will be drilled and completed in a period of 10.5 months. Table 3-3 shows the blowout frequency for the SWRX project based on these well operations and the general frequency per operation shown in Table 3-1. Note that the frequencies presented in Table 3-3 are for the actual drilling period of 10.5 months, rather than for an entire year.

SWRX	Deep Reservoir		
Blowout Type	*Drillpipe*	*Annulus*	*Unconfined*
Drillfloor	4.08E-03	2.45E-03	5.10E-04
Subsea	3.16E-03		
	Shallow Gas		
Blowout Type	*Drillpipe*	*Annulus*	*Unconfined*
Drillfloor			
Subsea			8.00E-03

Table 3-3: Blowout Frequency Results for Duration of SWRX Operations

Table 3-4 shows the annualised blowout risks for the SWRX project, i.e. assuming that operations are being conducted continuously throughout a full year.

SWRX	Deep Reservoir		
Blowout Type	*Drillpipe*	*Annulus*	*Unconfined*
Drillfloor	4.80E-03	2.88E-03	6.00E-04
Subsea	3.72E-03		
	Shallow Gas		
Blowout Type	*Drillpipe*	*Annulus*	*Unconfined*
Drillfloor			
Subsea			9.42E-03

Table 3-4: Annualised Blowout Frequency Results for SWRX

3.3 Blowout Consequences

3.3.1 Blowout Hydrocarbon Release Rates

The consequences of a blowout incident will depend upon the size and location of the blowout. As stated previously two main blowout types are being considered, deep reservoir blowouts and shallow gas blowouts, resulting in releases subsea and at the drillfloor.

3.3.1.1 Deep Reservoir Blowouts

Historically, for deep reservoir blowouts occurring at the drillfloor the following flowrates are considered to be typical :

- Drillpipe Blowout 50kg/s
- Annulus Blowout 100kg/s
- Unconfined Blowout 250kg/s

A more detailed assessment was completed during the Project phase to assess the potential environmental impact of deep reservoir blowout incidents from White Rose wells [5]. This analysis used detailed modelling techniques to simulate a number of specific blowout scenarios. However, it was found that the results predicted by the detailed analysis did not cover all the scenarios shown above. In addition, for those scenarios that were similar, the outflow rate from the detailed analysis was lower than that predicted by the historical information. For this reason, the historical outflow rates were retained for this assessment to model blowouts at the drill floor.

For the deep reservoir release, the maximum subsea blowout rate quoted in the detailed analysis [5] was 36kg/s (32kg/s oil and 4kg/s gas). This value will be used in the consequence analysis.

3.3.1.2 Shallow Gas Blowouts

For the shallow gas blowout, a release rate based upon historical shallow gas blowouts is taken as 100MMSCFD (30kg/s) of methane.

3.3.2 Ignition Probability

If ignited, the potential for loss of life from any blowout incident increases dramatically.

Blowouts that do not ignite can result in large releases of hydrocarbons to the environment, however the threat to personnel and the MODU are generally considered to be low. Such events would only really threaten personnel if high levels of H_2S were released from the wellfluids, which is not the case for the White Rose field.

Using historical data within [4], between 1980 and 1993 a total (covering all well operations) of 120 blowout events were reported to have occurred in the North Sea and the Gulf of Mexico regions. Of these 120 incidents, 19 were reported to have ignited resulting in a fire. Based upon the above figures, an average ignition probability of 0.16 may be derived.

However, it should be noted that of these 120 blowouts, a significant proportion (around 30%) have been shallow gas blowouts which have been safely diverted. Where this is the case these incidents have been considered to be non-hazardous and therefore have been discounted.

If it is assumed that diverted blowouts do not ignite then the probability of ignition for undiverted blowouts is around 23% [19/0.7x120].

Reference [4] does not provide a breakdown or assessment of blowout ignition probability according to blowout location. Consequently, it will be assumed that the ignition probability for all blowouts, irrespective of location, will be 0.23.

3.3.3 Blowout Hazard Assessment

Although White Rose wellfluids do not contain significant concentrations of H_2S, there is still a threat of unignited gas entering Accommodation spaces on the MODU. As a result unignited releases have been examined within this section as well as ignited releases.

3.3.3.1 Drillfloor Blowouts

Ignited drillfloor blowouts would burn as jet fires which would be mostly vertical in orientation although there could be a degree of deflection through either wind effects or by the fire impinging on the drill derrick.

Consequence analysis has been conducted using in-house TORCH software [6] examining the impact of thermal radiation on the Accommodation and TEMPSC facilities of the MODU for each of the scenarios examined.

The results of this analysis are presented next in Table 3-5.

Blowout Rate	Wind Speed	Heat Flux at TR	Heat Flux at TEMPSC
50kg/s	0m/s 5m/s 10m/s	Low 50kW/m^2 70kW/m^2	Low 30kW/m^2 70kW/m^2
100kg/s	0m/s 5m/s 10m/s	Low 60kW/m^2 70kW/m^2	Low 40kW/m^2 70kW/m^2
250kg/s	0m/s 5m/s 10m/s	Low 70kW/m^2 >70kW/m^2	Low 70kW/m^2 >70kW/m^2

Table 3-5: Heat Fluxes Caused by Vertical Blowouts with Wind Toward the Accommodation

The above results have been generated by superimposing thermal radiation contour plots onto an elevation of the MODU. Example plots are presented in Appendix B showing the impact of drillpipe blowouts at the drillfloor with various wind speeds blowing towards the MODU Accommodation.

It is clear that some degree of heat flux will be experienced on most exposed areas of the installation due to the fires described above. Personnel exposed to such thermal radiation levels would suffer fatality.

However, it is worth noting that in the case of an impending reservoir blowout, adequate warning should, in most cases, be available which would result in all non-essential personnel being mustered in the TR either before hydrocarbons are released at the drillfloor or before ignition occurs.

3.3.3.2 Subsea Blowouts

Two blowout types have been considered here, the first being a shallow gas blowout which could occur whilst drilling the top hole, and the second being a release from either the wellhead or outside of the casing during deep drilling or completion of the well.

For both scenarios ignited releases can result in a sea pool fire whilst unignited releases can result in hydrocarbon gas being drawn into Accommodation spaces.

For small subsea releases, the diameter of the fire on the sea surface is calculated based on 1/5 x water depth. This approximate relationship is based on work reported in SINTEF's Fire Risk Assessment Manual [7] although this could potentially be an underestimate for larger releases [8]. An alternative fire diameter can also be modelled using a fireball model, calculating the diameter as $D = 6Q^{0.4}$ (Q = outflow rate in kg/s).

For the shallow gas release, the fire size on the sea surface will be the larger of the plume based model (assumed in 120m of water in the White Rose Area) and the fireball model.

For the deep reservoir blowout there is a further fire type to consider, this being an oil pool fire on the sea surface. Fire sizes for both scenarios are shown in Table 3-6.

Breach Size	Fire Type / Model Used	Fire Diameter
Shallow Gas	Gas Plume Model	24m
	Gas Fireball Model	23m
Deep Reservoir	Gas Plume Model	24m
	Gas Fireball Model (4kg/s Gas)	10m
	Oil Pool Fire Model (32 kg/s Oil)	24m

Table 3-6: Subsea Blowout Fire Sizes

Importantly, the smoke generated from these fires may have a significant effect on the MODU. This will only be problematic for the deep reservoir blowout as the amount of smoke generated by a well ventilated gas pool fire in the case of a shallow gas release will be small. For a well ventilated pool fire on the sea surface, the Carbon Monoxide (CO) production rate will be of the order of 0.5% or 5,000 ppm [9]. Table 3-7 shows the effects of different levels of CO on personnel.

Dispersion analysis has been conducted using the in-house PLUME software [10] and the results presented in Appendix B. The analysis shows the concentrations that could be expected on the MODU for the case where there is a 5m/s wind blowing the smoke towards the Accommodation. This is an idealised view of events as the plume contours assume free field dispersion. In reality the smoke will billow up around the sides of the vessel and through the moonpool.

Concentration	Effect
400ppm CO	Lower Toxicity Limit, hallucinations after 0.5-2 hours
800ppm CO	4m visibility (likely to prevent or discourage escape and evacuation)
3000ppm CO	Fatal after 30 minutes

Table 3-7: Effect of smoke concentration

Finally, unignited gas releases from a subsea blowout, and in particular a shallow gas blowout, could engulf the MODU in flammable gas with the potential for gas to be drawn into accommodation spaces and result in an explosion. Gas dispersion analysis using PLUME [10] has been conducted examining this scenario also. Results are presented in Appendix B for the cases where there is little or no wind and the case where 5m/s wind is blowing towards the accommodation.

3.4 Blowout Assessment Conclusion

The annual frequency of blowouts during the drilling and completion of the five new wells for the SWRX project is predicted to be **2.14×10^{-2}** per annum. This compares with a frequency of **1.73×10^{-2}** per annum for the assessment completed during the White Rose Project. The main reason for this increase is that there are 5 new wells being drilled at SWRX, whereas the 2005 drilling risks were based on the equivalent of 4 new wells being drilled. There are no drilling activities at the southern glory hole for the SWRX project and therefore there will be no associated blowout risks.

These blowout frequencies are carried forward to the MODU Risk Assessment (Section

5). The consequences of a blowout have been shown to be the same for SWRX operations as they were at the SGH.

This assessment is considered to be conservative as the blowout frequency and consequences from a water injection well are taken to be the same as a blowout from a production well. Any changes to the number or type of wells being drilled will have an affect on the frequencies and risks calculated here. This assessment shall therefore be reviewed as the SWRX Project moves into Detailed Design.

4 DROPPED OBJECT RISK ASSESSMENT

As a part of the SWRX safety assessment, a dropped object study has been carried out. This study determines the dropped object risks associated with creating the new glory hole, drilling the new wells and installing the items of equipment required for the new Drill Centre and tying this new equipment into the existing Southern Glory Hole.

The study investigates the potential for equipment to be dropped from the MODU during well operations or the DSV during the construction and hook-up phases of the project. For each Glory Hole (SWRX and SGH), the study estimates:

- The frequency of equipment being dropped in the area of the subsea equipment.
- The probability of dropped objects impacting the subsea equipment.
- The likelihood of dropped object impacts resulting in impairment of equipment i.e. impact energy greater than pipeline impact resistance.

4.1 Dropped Object Model

The dropped object model estimates:

- impact energies of falling objects;
- the likelihood (or probability) of dropped objects impacting on a given location;
- the probability that the dropped object will result in damage to the subsea targets.

It was assumed that all the lifts have a dropped object probability of 1×10^{-5} per lift, with the exception of the very heavy lifts of the xmas trees and the BOP which will have a dropped object probability of 2×10^{-4} per lift. These values have been extracted from the best available HSE dropped object data and are consistent with the previous dropped object study conducted for Husky [2] during the field development.

It should be recognised that there have already been two incidents in the White Rose field where the BOP has been dropped during the final positioning of the BOP within the glory hole. This would imply that the frequency of dropping the BOP should be higher for this particular MODU than the historical frequency suggests. However, it must also be remembered that this dropped object assessment is conservative in that it assumes all SWRX equipment is installed and live prior to any SWRX operations taking place. In addition, the MODU may continue to operate on the White Rose field for the remaining field life without dropping the BOP again.

A recommendation has therefore been made within this study to review the dropped object frequency for the BOP and include any appropriate changes within any future revisions of this report.

4.2 Crane Locations

It has been assumed that, whilst on-station above the new glory hole, 50% of the MODU lifts will be performed using the port-side crane and 50% with the starboard-side. Heavy lifts are performed through the moonpool. Very heavy lifts (xmas trees and BOP) which have a higher drop frequency will be performed with the MODU moved a distance of 60m off-station in order to reduce the risk of impact on the subsea equipment should the item be dropped. This off-set distance was previously assessed during the White Rose Project as being the optimum distance to move off station to reduce the potential for heavy lifts to impact on subsea equipment should they be dropped [2].

For the DSV, it has been assumed that the lifts are split 50:50 between the port and starboard cranes and that all lifts are carried out with the DSV located directly above the drill centre at which it is working.

4.3 Hydrodynamic Modelling

Hydrodynamic models for the study were based on extensive previous analysis of dropped objects using AQWA, Atkins' trajectory analysis program. From the results of these studies, it was found that the object types could be divided into broad categories with different responses to wave action, current flow and still water displacement. Again, the majority of the inputs assumed for this study are the same as those previously adopted for the existing MODU dropped object analysis [2], including sea current conditions etc.

4.4 Lift Manifests

A lift manifest has been created for each drill centre, to show the details of the objects to be lifted and the number of lifts, as shown in Table 4-1 & Table 4-2. The well operations manifest is based on the previous MODU dropped object study [2]. The manifest for the operations at SGH is based on information provided by the project [11]. Additionally, for the SWRX operations, the lift manifest shows the usage per zone – which is the proportion of lifts that will be carried out by each crane, where:

- SC represents the starboard-side crane (MODU located directly above the glory hole);
- PC represents the port-side crane (MODU located directly above the glory hole);
- MP represents a moonpool lift (MODU located directly above the glory hole);
- MP2 represents a moonpool lift (MODU located 60m North of the glory hole);
- SC2 represents the starboard-side crane (MODU located 60m North of the glory hole).

		Lifts /	weight	Length	Width /	Height	Usage Per Zone				
Item	**Hydro Model**	**Year**	**(kg)**	**(m)**	**Dia (m)**	**(m)**	**SC**	**PC**	**MP**	**MP2**	**SC2**
mini Container full	Small Container	1500	1620	1.83	1.52	2.44	0.5	0.5			
mini Container empty	Small Container	925	660	1.83	1.52	2.44	0.5	0.5			
maxi Container full	Medium Container	365	3350	3.05	2.44	2.44	0.5	0.5			
maxi Container empty	Medium Container	235	1140	3.05	2.44	2.44	0.5	0.5			
H/H Container full	Medium Container	95	3170	3.05	2.44	1.22	0.5	0.5			
H/H Container empty	Medium Container	50	990	3.05	2.44	1.22	0.5	0.5			
H/H Container full	Medium Container	95	4250	6.10	2.44	1.22	0.5	0.5			
H/H Container empty	Medium Container	85	1400	6.10	2.44	1.22	0.5	0.5			
Tote full	Small Container	140	4960	1.83	1.52	2.44	0.5	0.5			
Tote empty	Small Container	70	660	1.83	1.52	2.44	0.5	0.5			
Open Container full	Medium Container	50	5070	6.10	2.44	2.44	0.5	0.5			
Open Container empty	Medium Container	50	1890	6.10	2.44	2.44	0.5	0.5			
Closed Container full	Medium Container	50	4630	6.10	2.44	2.44	0.5	0.5			
Closed Container empty	Medium Container	140	1910	6.10	2.44	2.44	0.5	0.5			
Basket full	Mtbasket Data	95	1650	3.05	1.22	1.22	0.5	0.5			
Basket empty	Mtbasket Data	140	660	3.05	1.22	1.22	0.5	0.5			
Basket full	Mtbasket Data	95	2610	6.10	1.22	1.22	0.5	0.5			
Basket empty	Mtbasket Data	95	1110	6.10	1.22	1.22	0.5	0.5			
Basket full	Mtbasket Data	95	3040	9.14	1.22	1.22	0.5	0.5			
Basket empty	Mtbasket Data	95	1480	9.14	1.22	1.22	0.5	0.5			
Basket full	Mtbasket Data	50	3510	12.19	1.22	1.22	0.5	0.5			
Basket empty	Mtbasket Data	50	1850	12.19	1.22	1.22	0.5	0.5			
Helifuel Tank Full	Medium Container	20	6000	2.5	2.5	2.5	0.5	0.5			
Helifuel Tank Empty	Medium Container	20	2500	2.5	2.5	2.5	0.5	0.5			
5 7/8" Drill Pipe Bundle	TUBE06BNDDATA	50	2910	9.45	0.15		0.5	0.5			
9 1/2" Drill Collars Bundle	TUBE09BNDDATA	15	2952	9.45	0.24		0.5	0.5			
8 1/4" Drill Collars Bundle	TUBE09BNDDATA	15	4218	9.45	0.21		0.5	0.5			
6 1/2" Drill Collars Bundle	TUBE06BNDDATA	15	6327	9.45	0.165		0.5	0.5			
7" Tubing	TUBE06DATA	160	4353.75	12.5	0.179		0.5	0.5			
7" Liner Bundle of 9	TUBE09BNDDATA	50	4353.75	12.5	0.179		0.5	0.5			
7" Liner Single Shoe Joint	TUBE06DATA	10	4353.75	12.5	0.179		0.5	0.5			
30" Casing	TUBE30DATA	35	5765	12.5	0.762		0.5	0.5			
30" Casing Shoe Joint	TUBE30DATA	5	5765	12.5	0.762		0.5	0.5			
16" Casing	TUBE16DATA	55	3523	12.5	0.406		0.5	0.5			
16" Casing Shoe Joint	TUBE16DATA	5	1761.5	12.5	0.406		0.5	0.5			
13 3/8" Casing	TUBE13DATA	160	1265	12.5	0.34		0.5	0.5			
13 3/8" Casing Shoe Joint	TUBE13DATA	10	1265	12.5	0.34		0.5	0.5			
9 5/8" Casing	TUBE09DATA	200	995.25	12.5	0.244		0.5	0.5			
9 5/8" Casing Shoe Joint	TUBE09DATA	10	995.25	12.5	0.244		0.5	0.5			
5 7/8" HW Drill Pipe Joint	TUBE06DATA	30	2531	12.5	0.15		0.5	0.5			
5 7/8" Drill Pipe	TUBE06DATA	160	970	9.45	0.15		0.5	0.5			
Marine Riser Joint	Marine Riser Data	5	3000	15.55	0.5334		0.5	0.5			
Riser Slip Joint	PINCNT	5	18000	12.2	0.635		0.5	0.5			
PGB	X&SKD	5	3000	4.1	3.9	4.1	0.5	0.5			
Wellhead	TUBE36DATA	5	10000	10.67	0.914		0.5	0.5			
Xmas Tree	Xmas Tree	5	37000	4.1	3.9	4.1					1
Xmas Tree Frame	X&SKD	5	3000	4.1	3.9	4.1	0.5	0.5			
H.P.U Controls	HPU Controls	5	4000	2	1.2	1.2	0.5	0.5			
Spares Workshop Container	Medium Container	5	8000	6	2.8	2.8	0.5	0.5			
Container Completion Equipment	Small Container	5	8000	6	1.2	1.2	0.5	0.5			
Workshop Container	Large Container	5	8000	6	2.8	2.8	0.5	0.5			
Clamp Container	Medium Container	5	4000	6	2.8	2.8	0.5	0.5			
Power Tong Box	Medium Container	5	4000	3	2	2	0.5	0.5			
Handling Tools	Handling Tools	5	6000	10	8	4	0.5	0.5			
Jumper Basket	Mtbasket Data	5	4000	9	1.2	1.2	0.5	0.5			
Completion Equipment 1	Mtbasket Data	5	6000	17	1.2	1.2	0.5	0.5			
Completion Equipment 2	Mtbasket Data	5	6000	10	1.2	1.2	0.5	0.5			
Spare Cable Basket	Mtbasket Data	5	6000	10	1.2	1.2	0.5	0.5			
Completion Basket	Mtbasket Data	5	4000	20	4	4	0.5	0.5			
Choke Manifold	CTPP_MIU_TR	5	4000	2	2	1	0.5	0.5			
Pipe Basket	Large Container	15	4000	6	1.2	1.2	0.5	0.5			
Lubricator skid	CTPP_MIU_TR	10	6000	5	2	2	0.5	0.5			
High Pressure Pump	PP_SLF_HPP_P	5	4000	2	2	2.8	0.5	0.5			
Control Line Spooler	CT_I_EL	10	3000	2	2	2	0.5	0.5			
Chemical Injection Spooler	PP_SLF_HPP_P	10	5000	2	3	2	0.5	0.5			
Compressor	Air Compressor	15	12000	4	2	2	0.5	0.5			
Methanol Tank	Medium Container	5	2000	2	2	2	0.5	0.5			
surge tank	Large Container	10	5000	7	3	3	0.5	0.5			
internal subsea test tree	TUBE20DATA	10	5000	13	1.2		0.5	0.5			
Tubing Hangar	Marine Riser data	5	2000	3	1.3	1.3	0.5	0.5			
Tubing Hangar landing string accessories	Medium Container	5	1000	3	1.2	1.2	0.5	0.5			
Tubing Hangar landing string bundles	TUBE16BNDDATA	5	1000	3	1.2		0.5	0.5			
5 7/8" HW Drill Pipe Joint	TUBE06DATA	30	2530.612	12.5	0.15				1		
5 7/8" Drill Pipe	TUBE06DATA	160	970.068	9.45	0.15				1		
Marine Riser Joint	Marine Riser Data	220	3000	15.55	0.5334				1		
Riser Slip Joint	PINCNT	20	18000	12.2	0.635				1		
9 1/2" Drill Collar	DC_9_5	20	2952	9.45	0.24				1		
PGB	X&SKD	5	3000	4.1	3.9	4.1			1		
Xmas Tree + Frame + Wellhead	Xmas Tree	5	50000	4.1	3.9	4.1				1	
BOP	BOP	10	200000	4.1	4.8	12.5				1	
30" Casing	TUBE30DATA	35	5765	12.5	0.762				1		
30" Casing Shoe Joint	TUBE30DATA	5	5765	12.5	0.762				1		
16" Casing	TUBE16DATA	55	3523	12.5	0.406				1		
16" Casing Shoe Joint	TUBE16DATA	5	1761.5	12.5	0.406				1		
installation of manifold base	Extra Large Container	1	54000	22.68	12.48	4.464	0.5	0.5			
installation of SDU base	Extra Large Container	1	54000	22.68	12.48	4.464	0.5	0.5			
Piles	TUBE30DATA	8	8000	22	0.61		0.5	0.5			
S280 Piling Hammer c/w Sleeve	TUBE30DATA	8	26500	13.4	1		0.5	0.5			
Pile Follower	TUBE30DATA	8	3000	7.8	0.6		0.5	0.5			
installation of production manifold	Extra Large Container	1	20000	15.376	5.176	6	0.5	0.5			
Installation of SWRX WI manifold	Extra Large Container	1	20000	15.376	5.176	6	0.5	0.5			
installation of SWRX SDU	Extra Large Container	1	20000	15.376	5.176	6	0.5	0.5			
Rigid spool installation@SWRX to WI x-tree	TUBE16x2Data	2	10700	40	0.43		0.5	0.5			
Rigid spool installation@SWRX to Prod x-tree	TUBE16x2Data	3	10700	40	0.43		0.5	0.5			

Table 4-1: Lift Manifest for Operations at SWRX (from [2])

Item	Hydro Model	Lifts / Year	weight (kg)	Length (m)	Width / Dia (m)	Height (m)
30" Casing	TUBE30DATA	4	5600	12.2	0.762	0
glory hole levelling - air lift	TUBE36x2Data	2	2000	10	0.254	
installation of SDU base	Extra Large Container	1	54000	22.68	12.48	4.464
installation of SDU	Extra Large Container	1	20000	15.376	5.176	6
installation of extension manifold	Extra Large Container	1	20000	15.376	5.176	6
installation of WI expansion manifold	Extra Large Container	1	20000	15.376	5.176	6
SDC modifications, rigid spool installation	TUBE16x2Data	2	10700	40	0.43	
installation of WI tie-in spools	TUBE16x2Data	3	10700	40	0.43	
installation of WI weaklink arrangement (PBSJ) in SDC	Medium Container	2	3000	2.5	2.5	2.5

Table 4-2: Lift Manifest for Operations at SGH (from [11])

It should be noted that the SGH lift manifest information provided by the project [11] includes the lifting of a 30" section of casing. This casing will be deployed by the MODU whilst it is briefly located over the SGH. All other lifts will be carried out by the DSV or construction vessel at SGH. However, for simplicity, it is assumed that all dropped objects that occur at SGH will only affect the DSV and dropped objects at the SWRX will only affect the MODU.

Failure of the MODU mooring chains may also result in the chain falling on top of the flowlines. Similarly, mooring chains that run close to the flowlines could damage flowlines or umbilicals through abrasion. However, this was reviewed during the White Rose Project [12] with the conclusion that such damage was unlikely to result in loss of containment from the flowlines or damage to the umbilicals.

One other hazard introduced by the MODU that has not been assessed to date is that of drifting anchors. Whilst it is not a particular safety concern for this particular study, as the subsea SWRX equipment will not be live for the majority of the time that the MODU is present, it is recommend that the risk of anchor damage to the flowlines be assessed in more detail.

4.5 Subsea Equipment Targets

The equipment to be installed at the SWRX Glory Hole has been divided into eight target areas – the frequency of impact and/or damage to each of these targets will be determined separately. Figure 4-1 shows the division of the subsea equipment into target areas.

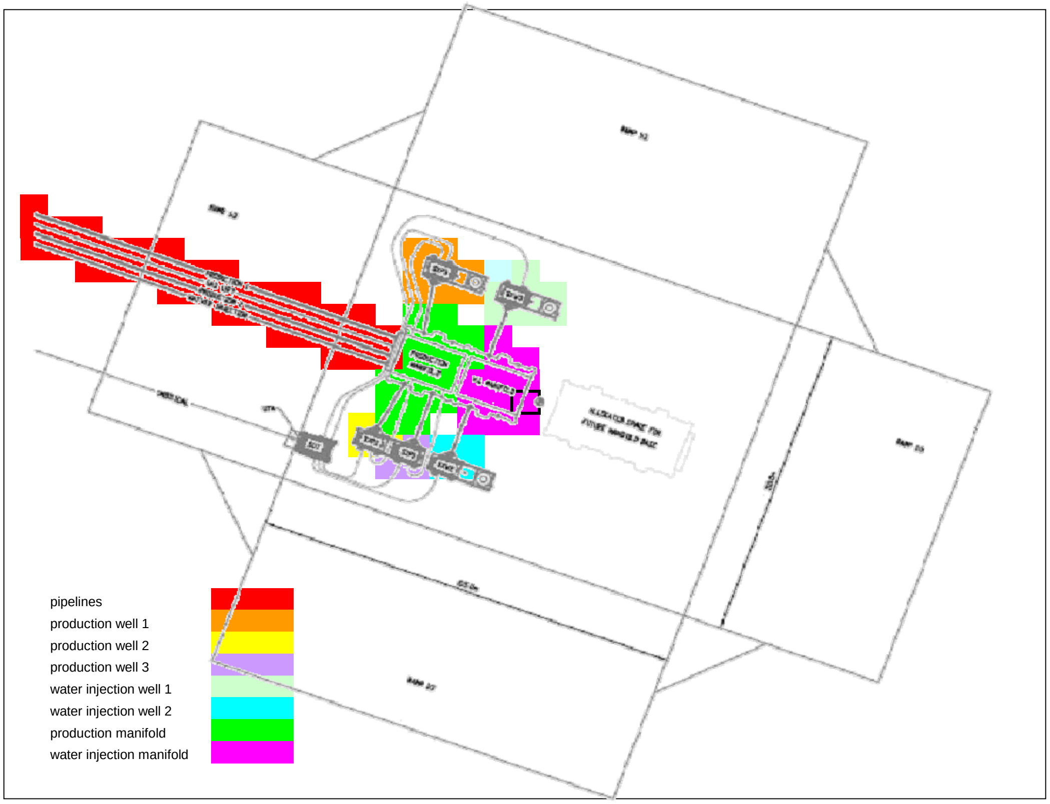

Figure 4-1: SWRX Glory Hole Subsea Equipment Targets

Similarly, the equipment at the SGH has been divided into eleven targets, as shown in Figure 4-2 below.

Figure 4-2: Southern Glory Hole Subsea Equipment Targets

4.6 Impact Frequency

Applying the number of lifts for each particular type of object modelled, and the probability of dropping the object, a frequency of dropped objects landing on any given area of the seabed can be predicted.

By defining the locations of all the subsea equipment targets in a grid structure relative to the locations of the cranes, the frequency of any dropped object landing on any given subsea target can be determined.

4.6.1 Annualised Impact Frequencies

Table 4-3 shows the frequency with which dropped objects may impact on the subsea equipment targets during the construction of the new SWRX glory hole. The actual impact frequency is based on the duration of the well operations (10.5 months); the annualised frequency is determined by increasing the actual frequency by a factor of 12/10.5.

Target #	Target Name	Actual Total Impact Frequency for SWRX Project	Total Annualised Impact Frequency (/yr)
1	pipelines	1.60E-03	1.89E-03
2	production well 1	1.47E-03	1.73E-03
3	production well 2	1.28E-04	1.51E-04
4	production well 3	8.09E-05	9.53E-05
5	water injection well 1	1.28E-03	1.51E-03
6	water injection well 2	1.34E-04	1.58E-04
7	production manifold	2.80E-03	3.30E-03
8	water injection manifold	1.88E-03	2.22E-03
	Total for SWRX	**9.39E-03**	**1.11E-02**

Table 4-3: Impact Frequency for Objects Dropped at SWRX

Similarly, Table 4-4 shows the frequency with which dropped objects may impact on the subsea equipment targets in the existing SGH glory hole during the modification activities related to the SWRX project. The DSV and construction operations are scheduled to take approximately 48 days and therefore the annualised risks are obtained by factoring the SWRX operation frequency by 365/48.

Target #	Name	Actual Total Impact Frequency for SWRX Project	Total Annualised Impact Frequency (/yr)
1	SW1-3	1.05E-06	7.98E-06
2	water injection manifold	4.76E-06	3.62E-05
3	SW 4-6	1.05E-05	7.95E-05
4	SDU	8.18E-06	6.22E-05
5	SP1/2/5	4.50E-07	3.42E-06
6	production manifold	1.94E-06	1.48E-05
7	SP3/4/6	6.17E-06	4.69E-05
8	pipelines	1.81E-07	1.38E-06
9	New SDU	7.82E-06	5.95E-05
10	SW7-8	1.81E-05	1.37E-04
11	flowlines from FPSO	2.27E-06	1.73E-05
	Total for SGH	**6.13E-05**	**4.66E-04**

Table 4-4: Impact Frequency for Objects Dropped at SGH

4.7 Damage Probability

The probability that impact results in damage is based on the probability of the dropped object hitting the target equipment with sufficient energy to cause impairment.

The damage probability rule sets, use the same principles that were applied in earlier dropped object studies for the White Rose development [2]. This method not only took credit for the dropped object damaging the subsea equipment by a direct hit but also took account of the object causing damage from an indirect hit (i.e. impact occurs outwith the centre of gravity of the object).

In the event of a dropped object impacting on the pipeline, there is the potential for the targets to be impaired. The probability of impairment is dependent on the impact energy of the object and the resistance of the pipeline. Energies greater than the capacity of the subsea equipment (section 4.7.1), have the potential to impair the equipment. Where the impact energy is greater than 3 times the equipment resistance, it is assumed that the probability of causing impairment is 1. Where the impact energy is between the resistance and 3 times that value, the probability of impairment on impact is interpolated linearly between 0 and 1.

4.7.1 Impairment Capacity of Subsea Equipment

Based on previous FE analysis of a dropped object striking subsea equipment, it was estimated that each of the targets could be damaged by an impact of 25kJ with the exception of the flowlines, which could be damaged by an impact of 5kJ. As a conservative estimate, it is assumed that this level of damage would be sufficient to cause a loss of hydrocarbon containment.

These damage values are also the same as those used in the existing MODU Dropped Object Study [2]. However, it should be noted that it is the intention of the SWRX Project to install protection on the flowlines and umbilical's up to 100m from the manifold in a similar manner to existing White Rose flowlines [13]. This should provide protection to the flowlines against impacts of 25kJ.

4.8 Impairment Frequency of the SWRX Subsea Targets

To estimate the total frequency of impairment from dropped object impact during the drilling and hook-up operations, the impact frequencies and impairment probabilities are considered (impairment frequency = impact frequency x impairment probability).

Table 4-5 shows the Impairment Frequency for the subsea equipment at the new glory hole as a result of dropped objects during the SWRX project.

Target #	Target Name	Actual Total Impairment Frequency for SWRX Project	Total Annualised Impairment Frequency (/yr)
1	pipelines	1.45E-03	1.71E-03
2	production well 1	6.17E-04	7.26E-04
3	production well 2	4.53E-05	5.33E-05
4	production well 3	2.31E-05	2.72E-05
5	water injection well 1	5.61E-04	6.61E-04
6	water injection well 2	4.80E-05	5.65E-05
7	production manifold	1.23E-03	1.45E-03
8	water injection manifold	8.66E-04	1.02E-03
	Total for SWRX	**4.85E-03**	**5.71E-03**

Table 4-5: Impairment Frequency for Objects Dropped at SWRX

It must be remembered that this assessment is conservative, as items dropped at the start of SWRX operations will not impact any subsea equipment as it is yet to be installed.

Table 4-6 shows the Impairment Frequency for the subsea equipment at the existing Southern glory hole as a result of objects dropped as a result of modifications to the SGH conducted as part of the SWRX project.

Target #	Name	Actual Total Impairment Frequency for SWRX Project	Total Annualised Impairment Frequency (/yr)
1	SW1-3	7.50E-07	5.70E-06
2	water injection manifold	4.25E-06	3.23E-05
3	SW 4-6	9.58E-06	7.28E-05
4	SDU	7.52E-06	5.72E-05
5	SP1/2/5	3.19E-07	2.43E-06
6	production manifold	1.56E-06	1.19E-05
7	SP3/4/6	5.57E-06	4.24E-05
8	pipelines	1.81E-07	1.38E-06
9	New SDU	7.17E-06	5.45E-05
10	SW7-8	1.68E-05	1.27E-04
11	flowlines from FPSO	2.27E-06	1.73E-05
	Total for SGH	**5.59E-05**	**4.25E-04**

Table 4-6: Impairment Frequency for Objects Dropped at SGH

The frequency of equipment damage at the SGH is significantly lower than the previously calculated frequency. This is due to the reduced activities that will be carried out at the SGH for the SWRX project, compared to the previous drilling operations.

4.9 Conclusions

The frequency of objects being dropped during lifting operations and impacting on subsea equipment with sufficient energy as to damage the equipment and cause a loss of containment is relatively low. The impairment frequency at the new SWRX Glory Hole (**5.71×10^{-3}** per annum) is significantly higher than that at the SGH (**4.25×10^{-4}** per annum), due to the higher number of lifts that will be performed.

The total annualised impairment frequencies are carried forward to the MODU (for SWRX) and DSV (for SGH) risk assessments in Sections 5 & 6 respectively. The impairment frequencies will be split evenly and added to the leak frequency for the subsea production and gas lift facilities events.

It should be remembered that this assessment is conservative as it assumes that items dropped onto subsea equipment above the impact design energy of the equipment will result in a release of hydrocarbons from the equipment. However, the majority of the SWRX equipment will not be live during these operations and the SGH equipment will be shut down and depressurised whilst critical operations take place. Whilst dropped objects may damage the subsea equipment, it is actually unlikely to result in a hydrocarbon release in this case. However, the leak frequency that has been carried forward to the risk assessment is shown in Table 4-7 below.

Event	Location	Small	Medium	Large
SS-03	Subsea Release from production manifold or flowlines at the Southern Drill Centre			2.13E-04
SS-04	Subsea Release from gas lift flowlines at the Southern Drill Centre			2.13E-04
SS-08	Subsea Release from production manifold or flowlines at the South White Rose Expansion			2.85E-03
SS-09	Subsea Release from gas lift flowline at the South White Rose Expansion			2.85E-03

Table 4-7: Additional Leak Frequency Due To Dropped Object Impairment

As the design progresses, any changes to the subsea layout or the lift manifest shall have to be reviewed and the corresponding dropped object risk updated.

5 MODU RISK ASSESSMENT

The analysis presented here is based upon the use of a semi-submersible MODU for planned development drilling and completion activities. This assessment has identified hazards to which MODU personnel will be exposed during the well operations in the SWRX project. The analysis has assessed the potential consequences of such hazards and subsequently determined the associated risk to personnel.

The assessment has been based upon the use of the Global Santa Fe (GSF) Grand Banks. This MODU has its own Safety Plan in place [15] which has been supported by QRA [14] and has previously conducted operations at the White Rose field. Further QRA analysis for the MODU operating at the White Rose field has also been completed [1, 3]. However, should the operations be planned for another MODU then this assessment shall have to be revised to ensure that the specific MODU risks are addressed.

This assessment therefore focuses on the risks or hazards that are different as a result of the operations on SWRX. Details on those risks or hazards that would be the same, irrespective of where the MODU is operating, are not discussed in detail here but reference is given to the previous studies.

The scope of the analysis focuses on risks to MODU personnel only. With respect to personnel on the SeaRose FPSO, the Southern drill centre is located approximately 2km from the FPSO and the new SWRX glory hole will be located a further 4km from the SDC. Consequence analysis, conducted previously for the White Rose project, has shown that there are no hydrocarbon events, originating from any of the new or existing drill centres, which could impact the FPSO.

The analysis presented in this report aims to identify the major threats to life and to quantify them as risks expressed as:

TRIF: Temporary Refuge Impairment Frequency (per annum) - the annual frequency with which the TR will be impaired within a specified time period. Within the MODU Safety Case [15], the specified time period is set as 60mins as it is considered that this would be sufficient time to conduct a controlled evacuation.

PLL: Potential Loss of Life (per annum) - number of expected fatalities per year on the installation;

IRPA: Individual Risk Per Annum - the annual probability of fatality of an individual member of an employment category.

The TR on the Global Santa Fe (GSF) Grand Banks is comprised of the accommodation module, however, the TR should not be considered as a box but as a system. In this respect, the following are all given consideration:

- availability of escape routes to the TR;
- availability of the TR in terms of structural support, integrity of containment and survivability of occupants in its internal environment;
- availability of evacuation routes from the TR and the evacuation facilities.

The risk parameters calculated have been broken down into the contributions made by each accident type to enable the major risk contributors to be identified.

The IRPA is calculated for four employment categories (drill crew, deck/maintenance crew, motorman, and catering/administration crew) which cover the range of activities on the installation.

This assessment has been based on the previous risk assessment [3] carried for the MODU operating in the White Rose field. It is assumed that the consequences of the events previously identified (e.g. blowouts, accommodation fires, subsea releases) will be identical for corresponding events at SWRX, but that the frequency of occurrence of each hydrocarbon event may be different and this is assessed in more detail next.

5.1 Hydrocarbon Events

Hydrocarbon releases that occur as a result of operations on SWRX can be broadly grouped into :

- Blowouts that may occur during drilling operations;
- Subsea releases from live process equipment adjacent to the well being drilled;
- Events that are specific to the MODU.

The likelihood and consequences of blowouts were discussed previously in Section 3. Those subsea process releases and MODU specific events that may occur are described next.

5.1.1 Subsea Process Events

Releases from subsea processing equipment may occur as a result of :

- releases from the subsea manifold and equipment,
- releases from subsea flowlines and flexible jumpers.

Releases from these equipment items can occur as a result of equipment failures or through impact events (e.g. dropped objects, fishing trawl net impact). However, it should again be remembered that the majority of the subsea processing equipment will not be live during the period that the SWRX operations are taking place as it will still be in the process of being installed.

5.1.1.1 Equipment Failures

The release frequency from subsea equipment/manifold was derived by tabulating the equipment items contained within each section using process and instrumentation information. At this stage the equipment / manifold information was based on that previously supplied for equipment at the Southern Glory Hole [3] and this shall be reviewed and revised for SWRX as the Project progresses.

The output of this equipment count was a data input sheet for each section detailing the number and dimensions of all equipment for that section, an example of which is shown in Figure 5-1. Failure rate data for each equipment item identified has been drawn from [16] to allow overall failure frequencies to be generated.

Equipment Description		Number of Components	Small	Medium	Large
Reciprocating Compressors					
Centrifugal Compressors					
Reciprocating Pump					
Centrifugal Pump (double seal)					
Pressure Vessels					
Shell & Tube Heat Exchangers (3)	Shell				
Shell & Tube Heat Exchangers (3)	Tubing				
Shell & Tube Heat Exchangers (3)	Combined				
Small Process Piping (/m)	< 3 inch				
Process Piping (/m)	4 inch				
Process Piping (/m)	6 inch				
Process Piping (/m)	8 inch				
Process Piping (/m)	10 inch	50	1.30E-03	3.56E-04	1.47E-04
Process Piping (/m)	11 inch				
Large Process Piping (/m)	> 12 inch				
Flange	<3 inch	12	1.02E-03	3.03E-05	3.45E-06
Flange	4 inch				
Flange	6 inch	36	3.05E-03	4.55E-05	7.69E-05
Flange	8 inch				
Flange	10 inch	1	8.46E-05	1.26E-06	2.14E-06
Flange	11 inch				
Flange	> 12 inch				
Valve	<3 inch	12	2.61E-03	1.31E-04	1.49E-05
Valve	4 inch				
Valve	6 inch	20	4.17E-03	2.44E-04	1.85E-04
Valve	8 inch				
Valve	10 inch	1	2.09E-04	1.22E-05	9.25E-06
Valve	11 inch				
Valve	> 12 inch				
Small bore fitting (2)		4	1.88E-03		
Total Leak Frequency (/yr) for Isolated Section			1.43E-02	8.21E-04	4.39E-04

Figure 5-1: Sample Failure Rate Input Sheet

This process has been repeated for each of the subsea events identified. Total release frequencies (per annum) for each set of subsea equipment is summarised in Table 5-1 below.

Event ID	Description	Leak Frequency (/yr)		
		Small	Medium	Large
8	Subsea Release from SWRX production manifold and wells	1.43E-02	8.21E-04	4.39E-04
9	Subsea release from SWRX gas lift manifold	1.05E-02	4.38E-04	4.97E-05

Table 5-1: Equipment Failure Rates for Subsea Manifolds and Wellheads (Flowlines and Flexible Jumpers Not Included)

For subsea flowlines and flexible jumpers the latest AME release frequency data [17] (see Table 5-2) has been applied.

	10mm	50mm	Full Bore	Total
Steel Pipeline	4.07E-04	9.90E-05	2.09E-04	7.15E-04
Flexible Pipeline	8.85E-04	1.40E-04	2.79E-04	1.30E-03

Table 5-2: Base Parloc 2001 [17] Pipeline Release Frequency Data

The above data is based upon a length of flowline equivalent to 500m (typical safety zone).

Since not all of the steel flowline releases will be sufficiently close to the MODU to impact the rig, the results of the consequence analysis conducted and presented in Appendix A, have been used to determine the proportion of the steel flowline releases which can impact the rig.

These are presented in Table 5-3 below.

Type of Flowline	Proportion of Releases Applicable		
	10mm	50mm	FB
Production Flowline	-	5%	25%
Gas Lift Flowline	-	5%	10%

Table 5-3: Proportion of Steel Flowline Releases Capable of Impacting the MODU

Flexible jumpers for the gas lift equipment are located between the manifolds and the wellheads therefore releases from these sections would be expected to be directly below the MODU when the MODU was on location. However the flexible line release frequencies reported in Table 5-2 above have not been factored to account for the estimated length of flexible line at each location which has been estimated to be around 50m, and therefore the frequencies need to be factored here.

Overall pipeline and flexible flowline release frequencies for each subsea event are thus calculated:

Medium (50mm) Releases From SWRX Gas Lift Flowlines & Flexible Jumpers:

Release Frequency = [0.05 x 9.9E-05 + 0.1 x 1.4E-04](Table 5-2, Table 5-3) *= 1.89E-05/yr*

Results are presented in Table 5-4.

Event ID	Description	Leak Frequency (/yr)		
		10mm	50mm	FB
8	Release from SDC Production Flowlines	-	4.95E-06	5.23E-05
9	Release from SDC Gas Lift Flowlines	8.85E-05	1.89E-05	4.88E-05

Table 5-4: Release Frequencies for Subsea Flowlines and Flexible Jumpers

Finally, subsea equipment failure rates and subsea flowline failure rates for each event have been summated. These failure rates are annual and therefore assume that the MODU is present for one full year of operations. The risks for the proportion of the year that the MODU shall spend at the SWRX Glory Hole shall also be reviewed in this assessment.

Equipment failure release frequencies for each event are thus presented in Table 5-5 below.

Event ID	Description	Leak Frequency (/yr)		
		10mm	50mm	FB
8	Subsea Release from SWRX Production Facilities	1.43E-02	8.26E-04	4.91E-04
9	Subsea Release from SWRX Gas Lift Facilities	1.06E-02	4.57E-04	9.86E-05

Table 5-5: Equipment Failure Subsea Hydrocarbon Events Release Frequencies

5.1.1.2 Dropped Objects

Loss of containment incidents could occur as a result of dropped objects from the MODU impacting subsea facilities (wellheads, manifolds etc.). The dropped object frequency was assessed previously in Section 4. It was determined that the frequency of dropped object incidents resulting in damage or release, whilst the MODU is located at SWRX, has been calculated to be:

- SWRX Production Facilities 2.85×10^{-3} per annum;
- SWRX Gas Lift Facilities 2.85×10^{-3} per annum.

Each of the above frequencies is based upon; the MODU being on location at that drill centre for the entire year; equal usage of the port and starboard cranes and the MODU being located directly over each well slot. It must be remembered that there will be no live hydrocarbon equipment beneath the MODU whilst performing SWRX operations and therefore the hydrocarbon leak frequency resulting from dropped objects is conservative.

If, however, it is assumed that such incidents are most likely to result in a large hydrocarbon release and if each release frequency is split evenly between the subsea hydrocarbon events at that drill centre, the following release frequencies, to be added to calculated release frequencies in Table 5-5 result.

Event ID	Description	Leak Frequency (/yr)		
		10mm	50mm	FB
8	Subsea Release from SWRX Production Facilities	-	-	2.85E-03
9	Subsea Release from SWRX Gas Lift Facilities	-	-	2.85E-03

Table 5-6: Subsea Hydrocarbon Events Release Frequencies as a Result of Dropped Object Incidents

5.1.1.3 Fishing Impacts

The threat of impact to subsea pipelines as a result of fishing activities at the White Rose field was previously examined in [18], during the Project phase.

This analysis concluded that there was a risk of fishing vessels operating in the White Rose region and damaging subsea pipelines as a result.

However, whilst it is recognised that subsea equipment (pipelines, wellheads etc.) could be damaged as a result of impact by fishing vessels trawl gear, the consequences for personnel on the MODU itself will be limited.

This is due to the fact that the area around the installation will be monitored for shipping movements in order to identify potential collision events as soon as possible. In addition exclusion zones around the MODU and the FPSO will be enforced by the standby vessel which should prevent any vessels including fishing vessels from operating close to either unit. There is also a constraint on how close trawl gear can get to the MODU location as a result of the anchor lines which do not touch down on the seabed until some distance out from the MODU. Thus in the unlikely event that damage did occur and a release of hydrocarbons resulted, the release would not impact either the MODU or the FPSO.

5.1.1.4 Overall Release Frequencies

Bringing together the equipment failure rates calculated in Section 5.1.1.1 and dropped object failure rates presented in Section 5.1.1.2, overall hydrocarbon release frequencies for subsea events are presented in Table 5-7 below.

Event ID	Description	Leak Frequency (/yr)		
		10mm	50mm	FB
8	Subsea Release from SWRX Production Facilities	1.43E-02	8.26E-04	3.34E-03
9	Subsea Release from SWRX Gas Lift Facilities	1.06E-02	4.57E-04	2.95E-03

Table 5-7: Overall Hydrocarbon Events Release Frequencies

5.1.1.5 Ignition Probabilities and Consequences

The ignition and explosion probabilities used in this QRA are based on the Cox, Lees and Ang model [19]. This model is based on naturally ventilated modules and is therefore appropriate for use for the MODU.

The ignition model makes use of the following equations to calculate the ignition probability:

$$P_{ignition} = e^{(0.392\ln(Q)-4.333)} \quad \text{for oil releases}$$

$$P_{ignition} = e^{(0.642\ln(Q)-4.16)} \quad \text{for gas releases}$$

where Q is the initial oil or gas release rate (kg/s).

The conditional explosion probability is calculated using the equation:

$$P_{\exp losion} = e^{(0.38\ln(Q)-2.995)}$$

where Q is the initial gas release rate or flash gas release rate from an oil release (kg/s).

Ignition probabilities for each release size are presented in Table 5-8 below.

Event ID	Description	Leak Frequency (/yr)		
		10mm	50mm	FB
8	Subsea Release from SWRX Production Facilities	-	0.048	0.080
9	Subsea Release from SWRX Gas Lift Facilities	-	0.132	0.300

Table 5-8: Ignition Probabilities for Subsea Releases

Releases from SWRX are assumed to be similar to releases from the SDC equipment and therefore the ignition probabilities are also assumed to be the same. The production and gas lift flowlines are longer than the SDC flowlines back to the FPSO. However, the fire sizes and durations from the SWRX flowlines are still of insufficient size and / or duration to result in loss of the MODU integrity.

The main threat to personnel on the MODU is therefore from the immediate effects of any fire on the sea surface that may result in high thermal radiation levels at the deck level.

Releases from the SWRX production and gas lift equipment have been included in the QRA model used previously for the MODU [3] to determine the risks to the MODU and personnel as a result of SWRX operations.

5.1.2 MODU Specific Hazards

Hazards that are specific to operations on the MODU include :

- Fire / Explosion in Mud Pit Room;
- Fire / Explosion in Shale Shaker House;
- Engine Room Fire;
- Helifuel Fire During Refuelling;
- Accommodation Fire.

These hazards were assessed in the MODU Safety Plan [15] and QRAs [3, 14] prepared previously. As they are not anticipated to change as a result of SWRX operations then they are not discussed in detail here. However, they have been included in the risk assessment to ensure that all of the risks on the MODU during SWRX operations are taken into account.

5.2 Non-Hydrocarbon Events

The following events have also been included in the assessment of SWRX MODU risks:

- Ship Collision
- Iceberg Collision
- Helicopter Travel
- Towing Incident
- Dropped Objects onto MODU
- Structural Failure
- Mooring Failure

- Extreme Weather
- Loss of Stability
- Occupational Risks

In a similar manner to the MODU Specific Hazards, a number of the non-hydrocarbon hazards have previously been assessed in the MODU Safety Plan [15] and QRA [3, 14] reports.

Whilst all of the above hazards have been included in the risk assessment, only those hazards that may change as a result of operations at SWRX have been described here in detail.

5.2.1 Helicopter Travel

Helicopter movements can be considered to generate two potential hazards. Firstly, the risk to personnel on board the helicopter if it crashes or ditches at sea and secondly the risk to the installation if the helicopter impacts it. Historically, helicopter risks have been dominated by fatalities amongst those on board the helicopter.

The transport risks are calculated on the basis that rig personnel working a three week on – three week off shift pattern will take 16 flights per year between the MODU and the shore base each year, and that each flight will last 2 hours.

Based on an analysis of the annual accident rates over the past 10 years for from the UK Civil Aviation Authority (CAA) [20], the following accident rates are applicable:

Accident Rate during take-off/landing = 3.10E-06 per flight stage

Accident Rate during flight = 5.57E-06 per hour flown

Fatality Fraction (crash during flight)	0.12
Fatality Fraction (crash during take off or landing	0.17

Based on the above data, the individual risk and PLL due to helicopter travel has been derived as follows:

IRPA = number of flights per year x (frequency of crash per hour x fatality fraction x flight duration + frequency of crash per take-off/landing x fatality fraction)

= 2.98×10^{-5} per annum

PLL = Number of personnel {number of flights per year x (frequency of crash per hour x fatality fraction x flight duration + frequency of crash per take-off/landing x fatality fraction)}/average offshore occupancy

= 5.61×10^{-3} fatalities per annum

Helicopter crash onto the helideck is likely to result in significant damage to the helicopter and may result in the release of helifuel onto the helideck. The helideck is equipped with local fire fighting equipment and therefore the potential for such an event to escalate and result in failure of the TR integrity is considered to be low. Similar, should the helicopter crash onto another area of the MODU, the potential for the event to escalate to the extent where the TR integrity is threatened is considered to be low.

5.2.2 Occupational Risk

The occupational risks relate to the hazards associated with performing work offshore, e.g.

hazards such as falls, crushing, mechanical impacts, electrocution, etc. The Fatal Accident Rates (FAR) used in the QRA are based on information presented in [21]. These FARs exclude marine, diving and helicopter risks.

Worker Group	Occupational FAR (per 10^8 working hours)
Drill Crew	12
Deck Crew	6
Motorman	6
Catering / Admin Crew	-
Divers	31

Table 5-9: Occupational Fatal Accident Rates (FAR)

There are no divers on the MODU, however their occupational risk is presented here for completeness and used in the DSV assessment shown in Section 6.

The FAR values are converted to individual risk per annum (IRPA) by taking into account the actual time each year that members of each employment category are exposed to the hazards at the workplace. For all employment categories, it is assumed that each individual spends 50% of their time offshore with 50% of his/her time at the workplace and the remaining 50% of the time in the accommodation. Assuming that an individual is only exposed during his/her time at the workplace offshore, the FARs when converted to IRPAs are calculated to be:

- drill crew 2.63 x 10^{-4} per annum;
- deck crew 1.31 x 10^{-4} per annum;
- motorman 1.31 x 10^{-4} per annum;
- catering negligible;
- divers. 6.81 x 10^{-4} per annum;

5.2.3 Ship Collision

There are a number of potential sources of vessel collision hazard to which the MODU could be exposed. These are:

- attendant vessels (supply boat, standby boats, shuttle tanker);
- errant vessels.

During the units period of operation at the SWRX Glory Hole, there will be standby and supply vessels in close proximity to the MODU. Supply boats will clearly be at most risk of colliding with the unit when it is alongside, either offloading or backloading equipment and supplies. Collision or contact is an ever present threat during such operations.

The standby boat could also collide with the MODU, although it will not normally be required to operate in close proximity to the unit.

Attendant vessels will be highly unlikely to be involved in a high velocity impact and so, given their smaller size (less than 5,000 Tonnes) will have relatively low impact energies. As a result it is considered that the energy of impact will be insufficient to cause significant damage to the unit.

The potential for powered 3rd party vessels, including fishing boats, to collide with and damage the MODU depends upon the frequency of vessel movements in the vicinity of the White Rose field and upon the types of shipping traffic prevalent. Mitigating measures exist to prevent a collision by a powered or drifting vessel. These primarily involve the monitoring of shipping movements in order to identify any potential collision events as soon as possible together with means for alerting and intervening, if necessary, to avert a collision.

There shall be an exclusion zone extending 50m from the MODU anchor pattern that fishing vessels are not permitted to fish within. In addition, as long as vessels contact the FPSO to inform them of their position, they may still pass through the White Rose field. As a result, if a vessel is on a converging course with the MODU and these measures fail then a collision could occur. As an emergency measure the MODU can also move off-station if an approaching vessel poses a threat of collision.

In the absence of site specific data the most comprehensive source of ship collision data for worldwide oil & gas activities is found in the Worldwide Offshore Accident Database [22].

This dataset has been used to determine the MODU ship collision risk as reported within the MODU Safety Case [15]. However, the same data set was also used for the SeaRose FPSO Safety Plan [23] following a more detailed review of the source data. For consistency, the data from the Safety Plan has been used in this assessment rather than the MODU Safety Case [15] information.

The frequency of severe or total loss ship collisions is therefore taken to be 5.3 x 10^{-5} per annum.

For MODU operations at the SWRX Glory Hole the resulting risk to personnel is presented in Table 5-10 below.

Event	**PLL**	**IRPA**			
		Drill	**Maintenance/ Deck**	**Motorman**	**Catering**
Ship Collision	1.63E-03	8.68E-06	8.68E-06	8.68E-06	8.68E-06

Table 5-10: Ship Collision Societal and Individual Risk Levels

These frequencies are generic and therefore it is recommended that a ship collision study for the SWRX Glory Hole be conducted to determine more accurately the risks to the MODU from vessel collision.

The ship collision frequencies that are included here are assumed to result in total loss or severe damage to the MODU to the extent where failure occurs relatively quickly and most likely within one hour. Ship impacts that result in damage to the MODU pontoons or legs to cause gradual loss of stability are assumed to be included within the Loss Of Stability risks.

5.2.4 Iceberg Collision

As the White Rose field is located off the coast of Newfoundland, there is the possibility of the MODU being struck by an iceberg with the consequences of such an impact potentially severe.

The iceberg threat to the FPSO and subsea flowlines has been previously examined within [24] and [18]. Within these analyses the return period for large icebergs in the White Rose area was found to be 465 years.

The event tree presented in Figure 5-2 demonstrates how the risk to the MODU of iceberg collision has been considered within this analysis.

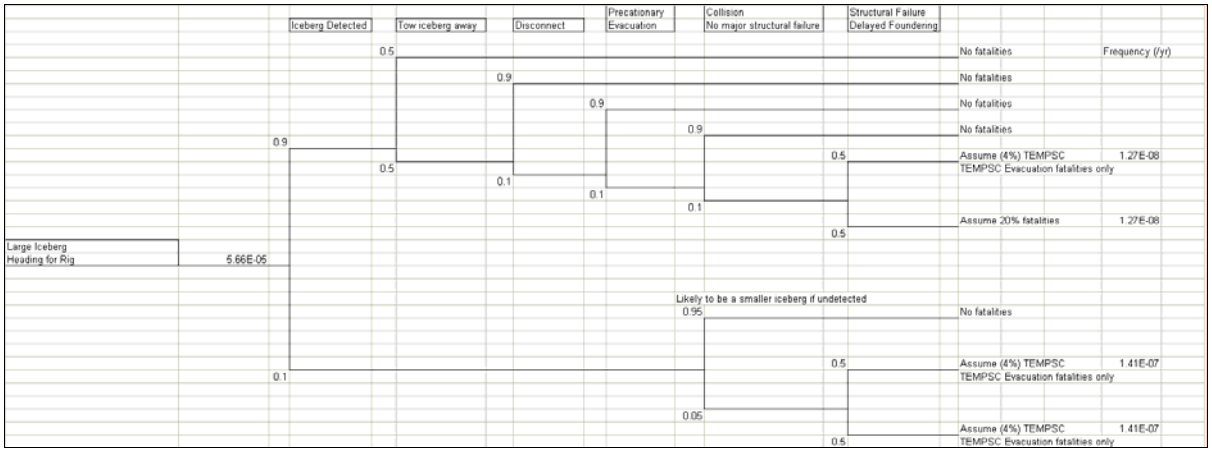

Figure 5-2: Iceberg Collision Event Tree

The frequency of hazardous outcomes and the potential fatality fraction following an iceberg collision are presented in Table 5-11.

Event	**Frequency (per year)**	**Fatality Fraction**
Iceberg collision resulting in rapid collapse	1.27×10^{-8}	0.2
Iceberg collision resulting in delayed foundering	2.96×10^{-7}	0.04

Table 5-11: Iceberg Collision Frequency and Fatality Fraction

For MODU operations at the SWRX Glory Hole the resulting risk to personnel is presented in Table 5-12 below.

Event	**PLL**	**IRPA**			
		Drill	**Maintenance/ Deck**	**Motorman**	**Catering**
Iceberg Collision	1.35E-06	7.19E-09	7.19E-09	7.19E-09	7.19E-09

Table 5-12: Iceberg Collision Societal and Individual Risk Levels

The frequency of iceberg impact, and resulting risk, is calculated on the basis that the potential for impact at the SWRX Glory Hole is the same as it shall be for any other location in the White Rose field. It is recommendation of this study that this assumption be reviewed in more detail to ensure that there potential for collision at SWRX is not significantly higher than at other locations in the field and that the collision management procedures still apply. Iceberg impacts considered within this section are assumed to result in loss of the TR integrity within the one hour endurance period of the MODU.

5.3 Personnel Distribution

The MODU has a typical POB of 94 during drilling operations with members of the rig crew operating on a three week rotation schedule. The personnel categories used to calculate Individual Risks are drill crew, maintenance/deck crew, motorman and catering/admin staff.

5.4 Results

The RISKMODEL summary output sheet is presented in Figure 5-3 next.

TR Impairment Frequency within 1 hr	**-**	**2.23E-04**	**Highest IRPA Total**	**-**	**6.50E-04**	**Drill Crew**
TR Impairment Frequency	**-**	**4.23E-04**	**Hydrocarbon IRPA**	**-**	**3.21E-04**	
Hydrocarbon PLL	**-**	**4.02E-02**	**Non Hydrocarbon IRPA**	**-**	**3.29E-04**	
Non Hydrocarbon PLL	**-**	**3.05E-02**	**Freq. HC Release**	**-**	**0.21230787**	
Total PLL	**-**	**7.07E-02**	**Freq. Ignited Events**	**-**	**0.008102788**	

		TR Impairment Freq. (TRIF) within 1 hr		Total TR Impairment Frequency (TRIF)		Potential Loss Of Life (PLL)		Drill		Maintenance / Deck		Motorman		Catering	
		TRIF (/Annum)	%	TRIF (/Annum)	%	PLL (Fats /a)	%	IRPA	%	IRPA	%	IRPA	%	IRPA	%
TR Impairment Mechanisms :															
	Derrick Collapse & Thermal	2.38E-05	10.7%	4.76E-05	11.3%										
	HVAC Failure - Gas	1.10E-05	4.9%	1.10E-05	2.6%										
	HVAC Failure - Smoke	3.78E-07	0.2%	3.78E-07	0.1%										
	RainOut			1.60E-06	0.4%										
	Sea Fire	1.51E-04	67.7%	3.02E-04	71.4%										
	Thermal Breach	2.37E-05	10.6%	4.74E-05	11.2%										
Calculated PLL :															
Hydrocarbon	Immediate					1.95E-02	27.6%	2.21E-04	34.0%			3.33E-04	52.5%		
	Muster														
	TR Fatalities					1.21E-02	17.1%	6.12E-05	9.4%	6.62E-05	20.8%	6.10E-05	9.6%	6.62E-05	38.6%
	Evacuation Fatalities					7.16E-03	10.1%	3.80E-05	5.9%	3.82E-05	12.0%	3.77E-05	5.9%	3.82E-05	22.3%
Hydrocarbon - Rig Specific	Fire/Explosion in Mud Pit Room	4.41E-10	0.0%	4.41E-10	0.0%	7.13E-07	0.0%	9.79E-10	0.0%	9.79E-10	0.0%	1.75E-08	0.0%	9.79E-10	0.0%
	Fire/Explosion in Shale Shaker House	1.99E-08	0.0%	1.99E-08	0.0%	1.79E-04	0.3%	3.65E-07	0.1%	3.65E-07	0.1%	3.82E-06	0.6%	3.65E-07	0.2%
	Fire - Engine Room	1.57E-08	0.0%	1.57E-08	0.0%	9.23E-05	0.1%	4.17E-07	0.1%	4.17E-07	0.1%	8.52E-07	0.1%	4.17E-07	0.2%
	Fire - Helicopter Fuel	1.43E-06	0.6%	1.43E-06	0.3%	1.16E-03	1.6%			1.59E-05	5.0%				
Non Hydrocarbon	Helicopter Travel					5.61E-03	7.9%	2.98E-05	4.6%	2.98E-05	9.4%	2.98E-05	4.7%	2.98E-05	17.4%
	Occupational					1.79E-02	25.3%	2.63E-04	40.5%	1.31E-04	41.3%	1.31E-04	20.7%		
	Loss of Stability					1.05E-03	1.5%	5.43E-06	0.8%	5.43E-06	1.7%	5.69E-06	0.9%	5.69E-06	3.3%
	Mooring Failure					5.89E-05	0.1%	3.06E-07	0.0%	3.06E-07	0.1%	3.17E-07	0.0%	3.17E-07	0.2%
	Loss of Tow					7.33E-05	0.1%	3.90E-07	0.1%	3.90E-07	0.1%	3.90E-07	0.1%	3.90E-07	0.2%
	Structural Failure					3.77E-03	5.3%	1.97E-05	3.0%	1.97E-05	6.2%	2.03E-05	3.2%	2.03E-05	11.8%
	Mechanical Failure - Lifting Equipment					3.96E-05	0.1%	6.18E-07	0.1%	6.18E-07	0.2%				
	Extreme Weather					3.28E-04	0.5%	6.33E-07	0.1%	7.35E-07	0.2%	7.35E-07	0.1%	7.35E-07	0.4%
	Ship Collision					1.63E-03	2.3%	8.68E-06	1.3%	8.68E-06	2.7%	8.68E-06	1.4%	8.68E-06	5.1%
	Iceberg Collision					1.35E-06	0.0%	7.19E-09	0.0%	7.19E-09	0.0%	7.19E-09	0.0%	7.19E-09	0.0%
	Fire - Accommodation	1.15E-05	5.2%	1.15E-05	2.7%	5.24E-05	0.1%	2.56E-07	0.0%	2.56E-07	0.1%	2.56E-07	0.0%	3.02E-07	0.2%
Hydrocarbon Total						4.02E-02	56.9%	3.21E-04	49.4%	1.21E-04	38.0%	4.36E-04	68.8%	1.05E-04	61.4%
Non Hydrocarbon Total						3.05E-02	43.1%	3.29E-04	50.6%	1.97E-04	62.0%	1.98E-04	31.2%	6.62E-05	38.6%
Totals		2.23E-04	100.0%	4.23E-04	100.0%	7.07E-02	100.0%	6.50E-04	100.0%	3.18E-04	100.0%	6.34E-04	100.0%	1.71E-04	100.0%

Figure 5-3: MODU Risk Model Results

5.4.1 TR Impairment Frequency (TRIF)

Two values of TRIF are calculated and presented in the results. Firstly the TRIF caused by hydrocarbon events which occur within the 1 hour endurance period of the TR are presented. The hydrocarbon events considered under this category are the very rapid impairments caused by failure of the HVAC system, sea fire events (which could occur as a result of subsea blowouts during drilling operations) which lead to fire impingement on unprotected steel supports for the TR, and events where the drill tower collapses causing a direct breach of the TR fabric. The Total MODU TRIF within 1 hour for the SWRX Project is **2.23×10^{-4}** per annum.

The total hydrocarbon TRIF is also presented which includes all events including those which occur after 1 hour. A time period of 1 hour is considered to be sufficient to allow a controlled evacuation of the MODU to take place. The Total Hydrocarbon MODU TRIF for the SWRX Project is **4.23×10^{-4}** per annum.

The TRIF presented here is per annum – the MODU operations for the SWRX project are predicted to last for approximately 10.5 months and therefore the actual TRIF (within 1 hr) for the project duration is **1.9×10^{-4}**.

The calculated TRIF for the representative impairment parameters are presented in Table 5-13.

Source	Within 1 Hour		Total	
	TRIF (per annum)	**%**	**TRIF (per annum)**	**%**
Derrick Collapse & Thermal	2.38E-05	11%	4.76E-05	11%
HVAC Failure - Gas	1.10E-05	5%	1.10E-05	3%
HVAC Failure - Smoke	3.78E-07	0%	3.78E-07	0%
RainOut	0.00E+00	0%	1.60E-06	0%
Sea Fire	1.51E-04	68%	3.02E-04	71%
Thermal Breach	2.37E-05	11%	4.74E-05	11%
Fire/Explosion in Mud Pit Room	4.41E-10	0%	4.41E-10	0%
Fire/Explosion in Shale Shaker House	1.99E-08	0%	1.99E-08	0%
Fire - Engine Room	1.57E-08	0%	1.57E-08	0%
Fire - Helicopter Fuel	1.43E-06	1%	1.43E-06	0%
Fire - Accommodation	1.15E-05	5%	1.15E-05	3%
	2.23E-04	**100%**	**4.23E-04**	**100%**

Table 5-13: Hydrocarbon TRIF Results for the Base Case

Table 5-14 below shows the contribution from each of the fire and explosion events to the overall hydrocarbon TR impairment frequency within one hour.

Event ID	Description	TRIF <1Hr	%
1	Mud Room Fire	4.41E-10	0.0%
2	Shaker Room Fire	1.99E-08	0.0%
3	Helifuel Fire	1.43E-06	0.6%
4	Engine Room Fire	1.57E-08	0.0%
5	Acommodation Fire	1.15E-05	5.2%
6	Subsea Release from SWRX Production Facilities	0.00E+00	0.0%
7	Subsea Release from SWRX Gas Lift Facilities	5.38E-06	2.4%
8	Subsea Blowouts at SWRX	1.57E-04	70.4%
9	Drillfloor Blowouts at SWRX	4.75E-05	21.3%
	Total	**2.23E-04**	**100.0%**

Table 5-14: TR Impairment Frequency Contribution for Fire and Explosion Events

The results show that the main contributors are blowout events, either subsea or on the drill floor. These account for a total of 92% of the TRIF within 1 hour and accommodation fires account for a further 5% of the TRIF.

Husky Oil has defined impairment-based criteria to distinguish between accidental events that have the potential to cause high-fatality accidents, and those which do not. High-fatality accidents are those where the consequences are sufficiently severe that they have the potential to escalate and cause fatalities to personnel other than those in the immediate vicinity of the incident.

Loss of integrity of the TR is defined as having occurred if, within 1 hour, there is:

- failure of external walls, allowing entry of fire and/or smoke.
- fire within the TR;
- deterioration of physical conditions within the TR which render it uninhabitable, that is, if there loss of breathable atmosphere, or intolerable heat build-up, etc.; and
- list, trim or heel in excess of 15 degrees.

The criteria applied to the impairment based TR integrity is :

- no single major accident hazard should result in failure of the integrity of the TR with a frequency higher than 1E-04 per annum;
- the total frequency of failure of the integrity of the TR should not exceed 1E-03 per annum for all major accident hazards.

The impairment based TR integrity is shown next for all events on the MODU that may cause loss integrity within the one hour endurance period.

Description	**Impairment Based TR Integrity (per annum)**	**%**
Mud Room Fire	4.41E-10	0.0%
Shaker Room Fire	1.99E-08	0.0%
Helifuel Fire	1.43E-06	0.3%
Engine Room Fire	1.57E-08	0.0%
Acommodation Fire	1.15E-05	2.3%
Subsea Release from SWRX Production Facilities	0.00E+00	0.0%
Subsea Release from SWRX Gas Lift Facilities	5.38E-06	1.1%
Subsea Blowouts at SWRX	1.57E-04	31.7%
Drillfloor Blowouts at SWRX	4.75E-05	9.6%
Mooring Failure	1.85E-06	0.4%
Loss of Tow	1.50E-05	3.0%
Structural Failure	1.01E-04	20.5%
Extreme Weather	1.00E-04	20.2%
Ship Collision	5.32E-05	10.8%
Iceberg Collision	3.08E-07	0.1%
Total	4.94E-04	100.0%

Table 5-15: MODU Impairment Based TR Integrity Frequency Contribution

It can be seen from Table 5-15 that the overall frequency of impairment of the TR integrity is below 1E-03 per annum. However, the frequency of subsea blowouts cause loss of the TR integrity exceed the 1E-04 per annum frequency for a single major accident hazard. Structural failures also exceed the 1E-04 per annum frequency, although it is marginal and considered not to be an issue for this assessment.

Subsea blowout frequencies are based on historical, generic information. As the MODU has been conducting well operations at the White Rose field for a number of years now, it could be argued that the drill crew on board will have a good knowledge of the reservoirs and therefore the historical values are likely to be conservative. Established procedures that are on place on the MODU for conducting well operations should also ensure that the risk of a subsea blowout occurring during SWRX operations is low.

5.4.2 Potential Loss of Life (PLL)

The total PLL for the MODU is **7.07×10^{-2}** fatalities per annum, of which 57% can be attributed to hydrocarbon events and 43% to non-hydrocarbon events.

The total PLL for the actual duration of the SWRX project is **6.02×10^{-2}** fatalities.

The different types of fatalities which make up the total PLL are shown in Table 5-16, and discussed below.

Source	PLL per Annum	%
Immediate Hydrocarbon	1.95E-02	28%
Delayed Hydrocarbon	1.92E-02	27%
Occupational	1.79E-02	25%
Helicopter Travel	5.61E-03	8%
Structural Failure	3.77E-03	5%
Hydrocarbon - Rig Specific	1.44E-03	2%
Ship Collision	1.63E-03	2%
Loss of Stability	1.05E-03	1%
Extreme Weather	3.28E-04	0%
Loss of Tow	7.33E-05	0.1%
Mooring Failure	5.89E-05	0.1%
Fire - Accommodation	5.24E-05	0.1%
Mechanical Failure - Lifting Equipment	3.96E-05	0.1%
Iceberg Collision	1.35E-06	0.0%
Total	**7.07E-02**	**100%**

Table 5-16: Potential Loss of Life (PLL) for SWRX Project

The PLL due to immediate fatalities accounts for 28% of the total PLL. The largest contributors to the immediate fatalities are those fatalities among essential personnel who would stay on the drill floor attempting to control a well incident. Other significant contributors to immediate fatalities are explosions in the shaker room and the mud pit area where an event can occur rapidly and cause fatalities in the immediate vicinity.

Delayed fatalities, which account for 27% of the total PLL, are either those associated with the need for TEMPSC usage if the TR is impaired or where a blowout has occurred, or are those associated with both the TR and the TEMPSC both being impaired leaving only tertiary means of escape available.

The greatest contributors to non-hydrocarbon risks involve the risks associated with offshore working. These are the helicopter travel between the shore and the MODU and the occupational (working) risks, which together amount to 33% of the overall PLL. Control of these hazards is not considered further in this analysis. The occupational risks (working accidents) for this installation are also high due to the high number of drill crew who traditionally have a high occupational risk associated with their jobs.

5.4.3 Individual Risk Per Annum (IRPA)

The risks to individual personnel on the MODU is dependent on worker category.

For the Drill Crew, the IRPA is **6.50×10^{-4}** per annum, for Maintenance/Deck Crew it is **3.18×10^{-4}** per annum. The Motorman Crew has an IRPA of **6.34×10^{-4}** per annum and the lowest risk group is the Catering/Admin Crew, whose IRPA is **1.71×10^{-4}** per annum.

The individual risks for the actual SWRX project duration are: Drill Crew **5.53×10^{-4}**, Maintenance/Deck Crew **2.71×10^{-4}**, Motormen **5.40×10^{-4}** and Catering/Admin Crew **1.46×10^{-4}**.

The breakdown of contributors to the IRPAs for the main worker categories on the MODU are presented below in Table 5-17.

Source	Drill Crew	%	Maintenance / Deck	%	Motorman	%	Catering	%
Immediate Hydrocarbon	2.21E-04	34.0%	0.00E+00	0.0%	3.33E-04	52.5%	0.00E+00	0.0%
Delayed Hydrocarbon	9.92E-05	15.3%	1.04E-04	32.8%	9.87E-05	15.6%	1.04E-04	60.9%
Hydrocarbon - Rig Specific	7.83E-07	0.1%	1.67E-05	5.2%	4.69E-06	0.7%	7.83E-07	0.5%
Helicopter Travel	2.98E-05	4.6%	2.98E-05	9.4%	2.98E-05	4.7%	2.98E-05	17.4%
Occupational	2.63E-04	40.5%	1.31E-04	41.3%	1.31E-04	20.7%	0.00E+00	0.0%
Loss of Stability	5.43E-06	0.8%	5.43E-06	1.7%	5.69E-06	0.9%	5.69E-06	3.3%
Mooring Failure	3.06E-07	0.0%	3.06E-07	0.1%	3.17E-07	0.0%	3.17E-07	0.2%
Loss of Tow	3.90E-07	0.1%	3.90E-07	0.1%	3.90E-07	0.1%	3.90E-07	0.2%
Structural Failure	1.97E-05	3.0%	1.97E-05	6.2%	2.03E-05	3.2%	2.03E-05	11.8%
Mechanical Failure - Lifting Equipment	6.18E-07	0.1%	6.18E-07	0.2%	0.00E+00	0.0%	0.00E+00	0.0%
Extreme Weather	6.33E-07	0.1%	7.35E-07	0.2%	7.35E-07	0.1%	7.35E-07	0.4%
Ship Collision	8.68E-06	1.3%	8.68E-06	2.7%	8.68E-06	1.4%	8.68E-06	5.1%
Iceberg Collision	7.19E-09	0.0%	7.19E-09	0.0%	7.19E-09	0.0%	7.19E-09	0.0%
Fire - Accommodation	2.56E-07	0.0%	2.56E-07	0.1%	2.56E-07	0.0%	3.02E-07	0.2%
Totals	**6.50E-04**	**100.00%**	**3.18E-04**	**100.0%**	**6.34E-04**	**100.0%**	**1.71E-04**	**100.0%**

Table 5-17: MODU IRPA Results for the SWRX Project

It can be seen that the IRPA for the Drill Crew or Motorman is much higher than that for the catering / administration staff. This is due to the immediate fatality risk which arises as a result of the time spent on the main deck, the drill floor or in other areas where hydrocarbon inventories are present.

The second effect is that associated with the occupational (working) risks associated with each worker group, with the drill crew having the highest contribution from this source due to their historical exposure as discussed above.

The other risk contributions follow the patterns discussed in for the PLL.

It should be noted that none of the individual risk levels for any of the worker groups examined exceed the individual risk Target Level of Safety of $1x10^{-3}$ per annum.

5.5 MODU Risk Assessment for Previous White Rose Activities

Figure 5-4 shows the risk levels that were previously calculated for the MODU carrying out drilling operations in the White Rose field. Details of the previous study are presented in [3], although the risk figures have been updated to incorporate revised dropped object frequencies, as detailed in [2].

It can be seen that the risk levels for the MODU carrying out drilling activities as part of the SWRX project are slightly higher than the previously calculated risks, primarily due to the increase in the number of wells to be drilled and completed.

Table 5-18 compares the main risk parameters for the SWRX project with those from the previous study.

RESULTS SUMMARY SHEET

TR Impairment Frequency within 1 hr	**-**	**1.82E-04**	**Highest IRPA Total**	**-**	**6.08E-04 Drill Crew**
TR Impairment Frequency	**-**	**3.39E-02**	**Hydrocarbon IRPA**	**-**	**2.85E-04**
Hydrocarbon PLL	**-**	**3.50E-02**	**Non Hydrocarbon IRPA**	**-**	**3.24E-04**
Non Hydrocarbon PLL	**-**	**2.99E-02**	**Freq. HC Release**	**-**	**0.207633037**
Total PLL	**-**	**6.49E-02**	**Freq. Ignited Events**	**-**	**0.007233496**

		TR Impairment Freq. (TRIF) within 1 hr		Total TR Impairment Frequency (TRIF)		Potential Loss Of Life (PLL)		Drill		Maintenance / Deck		Motorman		Catering	
		TRIF (/Annum)	%	TRIF (/Annum)	%	PLL (Fats /a)	%	IRPA	%	IRPA	%	IRPA	%	IRPA	%
TR Impairment Mechanisms :															
	Derrick Collapse & Thermal	2.17E-05	11.9%	4.33E-05	12.8%										
	HVAC Failure - Gas	4.75E-06	2.6%	4.75E-06	1.4%										
	HVAC Failure - Smoke	2.81E-07	0.2%	2.81E-07	0.1%										
	RainOut			1.45E-06	0.4%										
	Sea Fire	1.21E-04	66.3%	2.33E-04	68.8%										
	Thermal Breach	2.15E-05	11.8%	4.31E-05	12.7%										
Calculated PLL :															
Hydrocarbon	Immediate					1.74E-02	26.8%	2.01E-04	33.0%			2.93E-04	51.1%		
	Muster														
	TR Fatalities					1.04E-02	16.0%	5.24E-05	8.6%	5.69E-05	19.2%	5.22E-05	9.1%	5.69E-05	38.0%
	Evacuation Fatalities					5.74E-03	8.9%	3.05E-05	5.0%	3.07E-05	10.3%	3.03E-05	5.3%	3.07E-05	20.5%
Hydrocarbon - Rig Specific	Fire/Explosion in Mud Pit Room	4.41E-10	0.0%	4.41E-10	0.0%	7.13E-07	0.0%	9.79E-10	0.0%	9.79E-10	0.0%	1.75E-08	0.0%	9.79E-10	0.0%
	Fire/Explosion in Shale Shaker House	1.99E-08	0.0%	1.99E-08	0.0%	1.79E-04	0.3%	3.65E-07	0.1%	3.65E-07	0.1%	3.82E-06	0.7%	3.65E-07	0.2%
	Fire - Engine Room	1.57E-08	0.0%	1.57E-08	0.0%	9.23E-05	0.1%	4.17E-07	0.1%	4.17E-07	0.1%	8.52E-07	0.1%	4.17E-07	0.3%
	Fire - Helicopter Fuel	1.43E-06	0.8%	1.43E-06	0.4%	1.16E-03	1.8%			1.59E-05	5.4%				
Non Hydrocarbon	Helicopter Travel					5.61E-03	8.6%	2.98E-05	4.9%	2.98E-05	10.1%	2.98E-05	5.2%	2.98E-05	19.9%
	Occupational					1.79E-02	27.6%	2.63E-04	43.2%	1.31E-04	44.3%	1.31E-04	22.9%		
	Loss of Stability					1.05E-03	1.6%	5.43E-06	0.9%	5.43E-06	1.8%	5.69E-06	1.0%	5.69E-06	3.8%
	Mooring Failure					5.89E-05	0.1%	3.06E-07	0.1%	3.06E-07	0.1%	3.17E-07	0.1%	3.17E-07	0.2%
	Loss of Tow					7.33E-05	0.1%	3.90E-07	0.1%	3.90E-07	0.1%	3.90E-07	0.1%	3.90E-07	0.3%
	Structural Failure					3.77E-03	5.8%	1.97E-05	3.2%	1.97E-05	6.6%	2.03E-05	3.5%	2.03E-05	13.5%
	Mechanical Failure - Lifting Equipment					3.96E-05	0.1%	6.18E-07	0.1%	6.18E-07	0.2%				
	Extreme Weather					3.28E-04	0.5%	6.33E-07	0.1%	7.35E-07	0.2%	7.35E-07	0.1%	7.35E-07	0.5%
	Ship Collision					1.05E-03	1.6%	3.70E-06	0.6%	3.70E-06	1.2%	3.94E-06	0.7%	3.94E-06	2.6%
	Iceberg Collision					1.35E-06	0.0%	7.19E-09	0.0%	7.19E-09	0.0%	7.19E-09	0.0%	7.19E-09	0.0%
	Fire - Accommodation	1.15E-05	6.3%	1.15E-05	3.4%	5.24E-05	0.1%	2.56E-07	0.0%	2.56E-07	0.1%	2.56E-07	0.0%	3.02E-07	0.2%
Hydrocarbon Total						3.50E-02	53.9%	2.85E-04	46.8%	1.04E-04	35.1%	3.80E-04	66.3%	8.83E-05	59.0%
Non Hydrocarbon Total						2.99E-02	46.1%	3.24E-04	53.2%	1.92E-04	64.9%	1.93E-04	33.7%	6.15E-05	41.0%
Totals		1.82E-04	100.0%	3.39E-04	100.0%	6.49E-02	100.0%	6.08E-04	100.0%	2.97E-04	100.0%	5.73E-04	100.0%	1.50E-04	100.0%

Figure 5-4: Risk Assessment Results from Previous MODU Study

Risk Parameter	WR Development	SWRX Project	% Increase
TRIF (<1hr)	1.82×10^{-4}	2.23×10^{-4}	23%
PLL – Hydrocarbon	3.50×10^{-2}	4.02×10^{-2}	15%
PLL – Non-Hydrocarbon	2.99×10^{-2}	3.05×10^{-2}	2%
PLL – Total	6.49×10^{-2}	7.07×10^{-2}	9%
IRPA – Drill Crew	**6.08×10^{-4}**	**6.50×10^{-4}**	7%
IRPA – Maintenance/Deck	2.97×10^{-4}	3.18×10^{-4}	7%
IRPA – Motorman	5.73×10^{-4}	6.34×10^{-4}	11%
IRPA - Catering	1.50×10^{-4}	1.71×10^{-4}	14%

Table 5-18: Comparison of MODU Risks for SWRX with WR Development

5.6 Conclusions

The risk levels for the MODU carrying out the drilling activities for the South White Rose Expansion Project are predicted to be higher than the previously assessed risks for the MODU operating in the White Rose field during the development phase. However, the risk levels remain well below the Target Levels of Safety for TR impairment and individual risk.

The frequency of hydrocarbon TR impairment is 2.23×10^{-4} per annum, or once every 4,500 years, which is an increase of 23% on the TRIF calculated for the development phase of White Rose. The impairment based TR integrity frequency is calculated to be 4.94E-04 per annum, and includes all events capable of failing the integrity of the TR. The frequency of subsea blowouts causing failure of the TR integrity exceeds Husky's 1E-04 per annum criteria for a single major accident hazard. However, it is considered that the subsea blowouts risks are conservative when the history of the MODU at the White Rose field and established procedures in place are taken into account.

The total PLL has increased by 9% to 7.07×10^{-2} fatalities per annum or one fatality every 14 years. The highest risk worker category remains the Drill Crew, with an IRPA of 6.50×10^{-4} per annum – an increase of 7%.

The main cause of the increased risks is the higher number of wells to be drilled and completed in the operational year. Previously, the risks relating to the year with the highest planned drilling activities were included - this was predicted to be 2005 - where the equivalent of 4 wells were to be drilled and 7 completed (see Section 3.1.1). The SWRX project involves the drilling and completion of 5 wells in a 10.5 month period – equivalent to 5.9 in a year. The blowout frequency associated with the drilling of wells is higher than that for well completion and therefore the overall risks associated with blowouts has increased.

Overall, although the risks for the SWRX project are higher than those previously calculated for the MODU operating in the White Rose field, the TRIF and the maximum IRPA remain significantly lower than Husky's Target Levels of Safety (TLS) of 1E-03 per annum.

6 DSV RISK ASSESSMENT

The DSV risk assessment investigates the risks to personnel on board the DSV whilst it is on-station at the Southern Drill Centre, to allow modifications relating to the SWRX project to be carried out. There shall be a requirement for a DSV and a construction vessel to complete the installation of subsea equipment at both the Southern and SWRX Glory Holes. However, for simplicity within this assessment, it is assumed that the DSV will be performing all operations. In addition, the risks to the DSV from subsea hydrocarbon equipment releases are taken to be represented by the Southern Glory Hole equipment as there is likely to be a greater proportion of equipment live at SGH during DSV operations that at SWRX. This assessment is therefore conservative.

The DSV risk assessment has been carried out in exactly the same way as the MODU risk assessment, but with non-applicable risks removed. Again, the DSV or construction vessel would have a Safety Plan in place before commencement of operations. This review has therefore focussed on the specific hazards and risks introduced through operation on the SWRX project.

The consequences, in terms of effects on personnel (immediate / delayed fatalities) and on TR impairment mechanisms (fires, smoke etc.) are assumed to be the same for events occurring on the DSV as for those occurring on the MODU.

6.1 Hydrocarbon Events

The events of interest in this study are the subsea releases from the production and gas lift facilities at the Southern Drill Centre, fires in the Engine Room and the Accommodation There are no drilling activities to be carried out at the SGH and therefore no blowout events are considered in this assessment. Similarly, there can be no Mud Pit Room or Shaker Room hazards as these areas are specific to a MODU. The impairment frequency of the subsea equipment at the SDC due to dropped objects (as determined in Section 4) has been incorporated into the release frequencies for the SDC production and gas lift facilities.

Table 6-1 shows the list of hydrocarbon events considered in the DSV Risk Assessment for the SWRX operations and the release frequencies.

	Frequency (per annum)		
Event	**10mm**	**50mm**	**FB**
Engine Room Fire			2.78E-04
Accommodation Fire			4.40E-04
Subsea Release from SDC Production Facilities	1.43E-02	8.26E-04	6.41E-04
Subsea Release from SDC Gas Lift Facilities	1.06E-02	4.57E-04	2.48E-04

Table 6-1: Hydrocarbon Events – DSV Risk Assessment

The closer proximity of the engine room to the DSV accommodation means that the likelihood of impairing the TR has been increased over the value assumed for the MODU. For the DSV, it is assumed that 1% of all engine fires may result in impairment of the TR. This provides an impairment frequency similar to that calculated for the SeaRose FPSO [23].

6.2 Non-Hydrocarbon Events

The following events have been included in the SWRX DSV Risk Assessment, with information taken from the MODU Risk Assessment section :

- Ship Collision
- Iceberg Collision
- Extreme Weather
- Structural Failure
- Occupational Risks

Mooring Failure, Towing Incidents and Loss of Stability events have been removed from the DSV risk assessment as they do not apply to the DSV. It is also assumed that there shall be no helicopter transport risks as the vessel will return to shore during the period of operations. In reality, there may be a requirement to perform a small number of helicopter transits during the period of operations. However, these are not expected to significantly affect any of the risk levels reported here.

6.3 Personnel Distribution

The DSV has a typical POB of 90 during operations. The personnel categories used to calculate Individual Risks are divers, maintenance/deck crew and catering/admin staff.

6.4 Risk Assessment Results

Figure 6-1 below shows the results of the DSV risk assessment for the SWRX project. Note that these risks have been annualised.

TR Impairment Frequency within 1 hr	**-**	**1.49E-05**	**Highest IRPA Total**		**-**	**7.07E-04**	**Divers Crew**
TR Impairment Frequency	**-**	**1.49E-05**	**Hydrocarbon IRPA**	**-**		**7.36E-07**	
Hydrocarbon PLL	**-**	**1.80E-04**	**Non Hydrocarbon IRPA**	**-**		**7.06E-04**	
Non Hydrocarbon PLL	**-**	**4.92E-02**	**Freq. HC Release**		**-**	**0.027110328**	
Total PLL	**-**	**4.94E-02**	**Freq. Ignited Events**		**-**	**0.000225606**	

		TR Impairment Freq. (TRIF) within 1 hr		Total TR Impairment Frequency (TRIF)		Potential Loss Of Life (PLL)		Divers		Maintenance / Deck		Catering/Admin	
		TRIF (/Annum)	%	TRIF (/Annum)	%	PLL (Fats /a)	%	IRPA	%	IRPA	%	IRPA	%
TR Impairment Mechanisms :													
	HVAC Failure - Gas	6.52E-07	4.4%	6.52E-07	4.4%								
	HVAC Failure - Smoke												
	RainOut												
	Sea Fire												
	Thermal Breach												
Calculated PLL :													
Hydrocarbon	Immediate												
	Muster												
	TR Fatalities												
	Evacuation Fatalities					2.35E-06	0.0%	1.30E-08	0.0%	1.30E-08	0.0%	1.30E-08	0.1%
Hydrocarbon - DSV Specific	Fire - Engine Room	2.78E-06	18.6%	2.78E-06	18.6%	1.77E-04	0.4%	7.23E-07	0.1%	2.11E-06	1.3%	7.23E-07	2.8%
Non Hydrocarbon	Occupational					4.40E-02	89.0%	6.81E-04	96.4%	1.31E-04	82.9%		
	Structural Failure					3.77E-03	7.6%	1.97E-05	2.8%	1.97E-05	12.4%	2.03E-05	78.0%
	Mechanical Failure - Lifting Equipment					3.96E-05	0.1%	6.18E-07	0.1%	6.18E-07	0.4%		
	Extreme Weather					3.28E-04	0.7%	6.33E-07	0.1%	7.35E-07	0.5%	7.35E-07	2.8%
	Ship Collision					1.05E-03	2.1%	3.70E-06	0.5%	3.70E-06	2.3%	3.94E-06	15.1%
	Iceberg Collision					1.29E-06	0.0%	7.19E-09	0.0%	7.19E-09	0.0%	7.19E-09	0.0%
	Fire - Accommodation	1.15E-05	77.0%	1.15E-05	77.0%	5.24E-05	0.1%	2.56E-07	0.0%	2.56E-07	0.2%	3.02E-07	1.2%
Hydrocarbon Total						1.80E-04	0.4%	7.36E-07	0.1%	2.13E-06	1.3%	7.36E-07	2.8%
Non Hydrocarbon Total						4.92E-02	99.6%	7.06E-04	99.9%	1.56E-04	98.7%	2.53E-05	97.2%
Totals		1.49E-05	100.0%	1.49E-05	100.0%	4.94E-02	100.0%	7.07E-04	100.0%	1.59E-04	100.0%	2.60E-05	100.0%

Figure 6-1: DSV Risk Assessment Results

6.4.1 DSV TR Impairment Frequency (TRIF)

There are very few contributors to TR impairment – the total hydrocarbon TRIF is just **1.49×10^{-5}** per annum, all of which are assessed to occur within one hour. Fires in the Accommodation (77%), unignited gas ingress from subsea releases (4%) and fires in the Engine Room (19.0%) account for 100% of the TRIF.

The TRIF for the actual duration of the SWRX project activities at the SDC will be significantly lower, as the DSV will only be on-station for 48 days to carry out these activities. The actual duration TRIF is **1.96×10^{-6}**.

In a similar manner to the MODU risks, the DSV impairment based TR integrity frequency has also been calculated and is shown in Table 6-3.

Description	**Impairment Based TR Integrity (per annum)**	**%**
Subsea Release from SDC Production Facilities	0.00E+00	0.0%
Subsea Release from SDC Gas Lift Facilities	6.52E-07	0.2%
Engine Room Fire	2.78E-06	1.0%
Accommodation Fire	1.15E-05	4.3%
Structural Failure	1.01E-04	37.5%
Extreme Weather	1.00E-04	37.1%
Ship Collision	5.32E-05	19.7%
Iceberg Collision	3.08E-07	0.1%
Total	2.69E-04	100.0%

Table 6-2: DSV Impairment Based TR Integrity Frequency Contribution

The total impairment frequency is below the impairment based criteria of 1E-03 per annum for all major accident events. In a similar manner to the MODU, the frequency of structural damage exceeds the 1E-04 per annum limit placed on individual major accident hazards, although in this case it is marginal.

6.4.2 DSV Potential Loss of Life (PLL)

The total PLL for the DSV is **4.94×10^{-2}** fatalities per annum, of which 0.4% can be attributed to hydrocarbon events and 99.6% to non-hydrocarbon events.

The total PLL for the actual duration of the SWRX project is **6.50×10^{-3}**.

The different types of fatalities which make up the total PLL are shown in Table 6-3, and discussed below.

Source	PLL per Annum	%
Occupational	4.40E-02	89.0%
Structural Failure	3.77E-03	7.6%
Immediate Hydrocarbon	0.00E+00	0.0%
Hydrocarbon - DSV Specific	1.77E-04	0.4%
Ship Collision	1.05E-03	2.1%
Extreme Weather	3.28E-04	0.7%
Fire - Accommodation	5.24E-05	0.1%
Mechanical Failure - Lifting Equipment	3.96E-05	0.1%
Iceberg Collision	1.29E-06	0.0%
Delayed Hydrocarbon	2.35E-06	0.0%
Total	**4.94E-02**	**100%**

Table 6-3: Potential Loss of Life (PLL) on DSV for SWRX Project

The greatest contributors to the PLL are the non-hydrocarbon risks associated with offshore working and primarily occupational (working) risks, which amounts to 89% of the overall PLL. Control of these hazards is not considered further in this analysis. The occupational risks (working accidents) for this installation are also high due to the high number of divers who traditionally have a high occupational risk associated with their jobs.

6.4.3 DSV Individual Risk Per Annum (IRPA)

The Individual Risk Per Annum (IRPA) to personnel on the DSV is dependent on worker category.

For the Dive Crew, the IRPA is **$7.07x10^{-4}$** per annum, for Maintenance/Deck Crew it is **$1.59x10^{-4}$** per annum whilst the lowest risk group is the Catering/Admin Crew, whose IRPA is **$2.60x10^{-5}$** per annum.

The individual risks for the actual SWRX project duration are: Dive Crew **$9.30x10^{-5}$**, Maintenance/Deck Crew **$2.09x10^{-5}$** and Catering/Admin Crew **$3.42x10^{-6}$**.

The breakdown of contributors to the IRPAs for the main worker categories on the DSV are presented below in Table 5-17.

	Dive Crew	%	Maintenance/ Deck	%	Catering	%
Immediate Hydrocarbon	0.00E+00	0.0%	0.00E+00	0.0%	0.00E+00	0.0%
Delayed Hydrocarbon	1.30E-08	0.0%	1.30E-08	0.0%	1.30E-08	0.1%
Hydrocarbon - Rig Specific	7.23E-07	0.1%	2.11E-06	1.3%	7.23E-07	2.8%
Occupational	6.81E-04	96.4%	1.31E-04	82.9%	0.00E+00	0.0%
Structural Failure	1.97E-05	2.8%	1.97E-05	12.4%	2.03E-05	78.0%
Mechanical Failure - Lifting Equipment	6.18E-07	0.1%	6.18E-07	0.4%	0.00E+00	0.0%
Extreme Weather	6.33E-07	0.1%	7.35E-07	0.5%	7.35E-07	2.8%
Ship Collision	3.70E-06	0.5%	3.70E-06	2.3%	3.94E-06	15.1%
Iceberg Collision	7.19E-09	0.0%	7.19E-09	0.0%	7.19E-09	0.0%
Fire - Accommodation	2.56E-07	0.0%	2.56E-07	0.2%	3.02E-07	1.2%
Totals	**7.07E-04**	**100.00%**	**1.59E-04**	**100.0%**	**2.60E-05**	**100.0%**

Table 6-4: DSV IRPA Results for the SWRX Project

It can be seen that the IRPA for the Dive Crew is the highest. This is primarily due to the nature of the activities that divers will be involved in their day to day activities.

The other risk contributions follow the patterns discussed in for the PLL.

It should be noted that none of the individual risk levels for any of the worker groups examined exceed the individual risk Target Level of Safety of $1x10^{-3}$ per annum.

6.5 Conclusions

The risk levels for the DSV carrying out the installation and hook-up activities for the South White Rose Expansion Project are predicted to be low.

The frequency of hydrocarbon TR impairment is **$1.49x10^{-5}$** per annum, or once in 67,114 years. The impairment based TR integrity frequency is calculated to be $2.69x10^{-4}$ per annum should all hazards that may impair the DSV TR be taken into account. The total PLL is **$4.94x10^{-2}$** per annum or one fatality every 20 years. The highest risk worker category is the Dive Crew, whose IRPA is calculated to be **$7.07x10^{-4}$** per annum.

It should be noted, however, that these risk figures assume continuous operation throughout a full year. The operations that are to be carried out by the DSV for the South White Rose Expansion Project are predicted to last for just 48 days. The risks for the actual period of operation can therefore be calculated; the TRIF is predicted to be **$1.96x10^{-6}$**, the PLL to be **$6.40x10^{-3}$** and the maximum individual risk to be **$9.30x10^{-5}$**.

The risks associated with DSV operations during the SWRX project shall be reviewed and updated as the design progresses.

7 REVIEW OF FPSO MODIFICATIONS

The SWRX project shall result in minimal topsides changes to the SeaRose FPSO. However, the tie-in of the SWRX flowline to the SDC production manifold may result in additional SWRX flowline inventory being released at the FPSO if an accidental release occurred from the SDC production flowline.

The additional 5.1km of SWRX flowline inventory has been included in the SDC flowline inventory that was modelled in the White Rose Fire Risk Analysis [25] and the hydrocarbon release rates, fire sizes and durations re-assessed.

The results are shown in Table 7-1 in terms of jet flame length versus release time. The release from the SDC flowline including the SWRX inventory is modelled as event R1A, the SDC flowline on its own is modelled as R2A. For comparison, a release from the gas injection riser is also shown as event R7A.

Riser ID	Riser Description	Release Size	**Jet Fire Length (m) with Time (mins)**									
			0mins	0.5	1	2	5	10	15	20	30	60
R1A	Above Sea Releases from 10" Production/Test	10mm	50	50	50	50	50	50	49	49	49	49
	#1 from SDC	50mm	218	215	214	209	208	200	194	187	174	141
	2 PHASE	Full Bore	1232	489	441	358	346	299	259	224	151	71
R2A	Above Sea Releases from 10" Production/Test	10mm	50	50	50	49	49	49	49	49	48	47
	#2 from SDC	50mm	218	215	212	198	193	172	153	136	108	54
	2 PHASE	Full Bore	1232	489	441	266	225	99				
R7A	Above Sea Releases from 5.5" Gas Injection to	10mm	26	26	26	26	26	26	26	26	26	25
	NDC	50mm	95	83	78	69	67	62	59	57	52	40
	GAS	Full Bore	265	88	83	71	69	64	60	57	52	38

Table 7-1: Comparison of Riser Fire Sizes and Durations

It can be seen that the inclusion of the SWRX flowline inventory has resulted in large flames lengths being sustained for longer. The jet flame lengths shown here are based on free field conditions and the flame would actually behave more like a fire ball due to the confinement within the turret. Irrespective of the flame behaviour, all releases from the SDC riser within the turret are off sufficient size and duration to cause structural damage, even without the additional SWRX inventory.

Whilst the consequences of a riser release within the turret are clearly severe, the potential frequency of a fire event occurring in the turret from a riser release is very small, approximately once every 50,000 years per riser.

The conclusions of previous White Rose safety studies do not therefore change as a result of the inclusion of the SWRX inventory. Namely that the consequences of a riser release within the turret are severe, but the potential frequency of such an event occurring are very low. However, a number of recommendations have been raised that should be reviewed in more detail by the Project :

1) The project should review the impact on blowdown rates for the SDC production / test and gas lift lines as a result of the inclusion of the SWRX field. Any increase in the blowdown rates and time may affect the time taken to release the riser buoy via the QCDC system in the turret during a controlled disconnect operation;
2) The ESD shut down times for the SWRX facilities should also be reviewed to ensure that the time to close valves at SWRX is optimised and does not prolong the period of packing that may occur at the FPSO after the riser ESD valves have closed in the turret.

8 CONCLUSIONS & RECOMMENDATIONS

8.1 Conclusions

The conclusions of this Safety Assessment of the South White Rose Expansion Project are as follows:

1) The overall risks associated with the MODU are higher for the SWRX project than previously calculated for the MODU operating at the three existing drill centres; this is primarily due to increased risks associated with blowouts as a result of the additional wells being drilled. The increase in risks is a result of the operations to expand the White Rose field. The actual operations conducted for SWRX represent similar hazards and consequences to those already completed for the development of the White Rose field.
2) The hydrocarbon TR Impairment Frequency has increased by 23% to $2.23x10^{-4}$ per annum, or once every 4,500 years. The total PLL has increased by 9% to $7.07x10^{-2}$ fatalities per annum or one fatality every 14 years. The IRPA for the highest risk worker category (the Drill Crew) has increased by 7% to $6.50x10^{-4}$ per annum.
3) The impairment based TR integrity frequency for the MODU is calculated to be 4.94E-04 per annum. The highest contributor to this frequency is from subsea blowouts which contribute approximately 1.5E-04 per annum.
4) In all cases, however, the TR impairment frequency and IRPA values remain significantly below Husky’s Target Levels of Safety (1E-03 per annum). The frequency of subsea blowouts exceeds Husky’s TLS for a single MAH of 1E-04 per annum. However, the frequency is based on generic, historical information that is likely to be conservative as the MODU has been operating in the White Rose field for a number of years with established procedures in place.
5) The annual frequency of blowouts during the drilling and completion of the five new wells for the SWRX project is predicted to be $\mathbf{2.14x10^{-2}}$ per annum. This compares with a frequency of $\mathbf{1.73x10^{-2}}$ per annum from the previous blowout assessment. The main reason for this increase is that there is the equivalent of 5.9 new wells being drilled in a one year period at SWRX, whereas previously the drilling risks were based on the equivalent of 4 new wells being drilled in the year 2005.
6) The frequency of objects being dropped during lifting operations on the MODU and impacting on subsea equipment with sufficient energy as to damage the equipment and cause a loss of containment is relatively low. The impairment frequency at the new SWRX Glory Hole is $\mathbf{5.71x10^{-3}}$ per annum. This is slightly lower than the $\mathbf{5.90x10^{-3}}$ calculated in the previous MODU Dropped Object Study for the SGH.
7) The risk levels for the DSV carrying out the installation and hook-up activities for the South White Rose Expansion Project are predicted to be low. The frequency of hydrocarbon TR impairment is $\mathbf{1.49x10^{-5}}$ per annum, or once in 67,114 years. The total PLL is $\mathbf{4.94x10^{-2}}$ per annum or one fatality every 20 years. The highest risk worker category is the Dive Crew, whose IRPA is calculated to be $\mathbf{7.07x10^{-4}}$ per annum.
8) As for the MODU, the TRIF and IRPA values for the DSV are significantly below Husky’s Target Levels of Safety (1E-03 per annum).

8.2 Recommendations

1) As the SWRX Project progresses it is recommended that this safety assessment is updated to reflect any changes that may occur to the design. It is particularly important that assumptions made within this study are reviewed and updated to ensure that the conclusions drawn remain valid.
2) A review of the traffic management procedures at the White Rose field should be undertaken by Husky to ensure that there are sufficient measures in place to protect the SWRX equipment, and any MODU working at the SWRX Glory Hole, from vessels passing through the field.
3) A White Rose specific field traffic survey should be undertaken to provide a better understanding of the vessels that may pass through the field. The results of this study should be used to develop a ship collision assessment that determines the collision risk to the FPSO as well as any MODU that may be operating in the field.
4) Husky should also review in more detail the potential for icebergs to cause damage or scouring of equipment in the SWRX Glory Hole or flowlines. This review should also include the Ice Management procedures to ensure that the SWRX equipment can be protected to a similar level as existing subsea equipment.
5) The project should review the impact on blowdown rates for the SDC production / test and gas lift lines as a result of the inclusion of the SWRX field. Any increase in the blowdown rates and time may affect the time taken to release the riser buoy via the QCDC system in the turret during a controlled disconnect operation;
6) The ESD shut down times for the SWRX facilities should also be reviewed to ensure that the time to close valves at SWRX is optimised and does not prolong the period of packing that may occur at the FPSO after the riser ESD valves have closed in the turret.
7) The BOP dropped object frequency is based on historical, generic records of such incidents. This frequency should be reviewed to ensure that specific incidents of dropped BOPs at the White Rose field are taken into account and the frequency revised in future revisions of this report if appropriate;
8) The potential for MODU mooring chains to damage the flowlines or umbilicals has previously been assessed by the White Rose project. However, the potential damage that drifting anchors could cause to the flowlines or umbilical has not been assessed and should be reviewed to ensure that the potential frequency of damage is acceptable. .

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APPENDIX A
DROPPED OBJECT IMPACT DIAGRAMS

IMPACT FREQUENCY DIAGRAMS

The following plots show the frequency of impact of dropped objects onto the subsea equipment at the SWRX or Southern Glory Holes. The following Frequency Key shows the colours that are used in the plots to represent various impact frequencies. Note that the frequencies shown in the plots represent the frequency of the objects hitting the subsea equipment but takes no account of the probability of damage or loss of containment occurring.

Frequency Key
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08

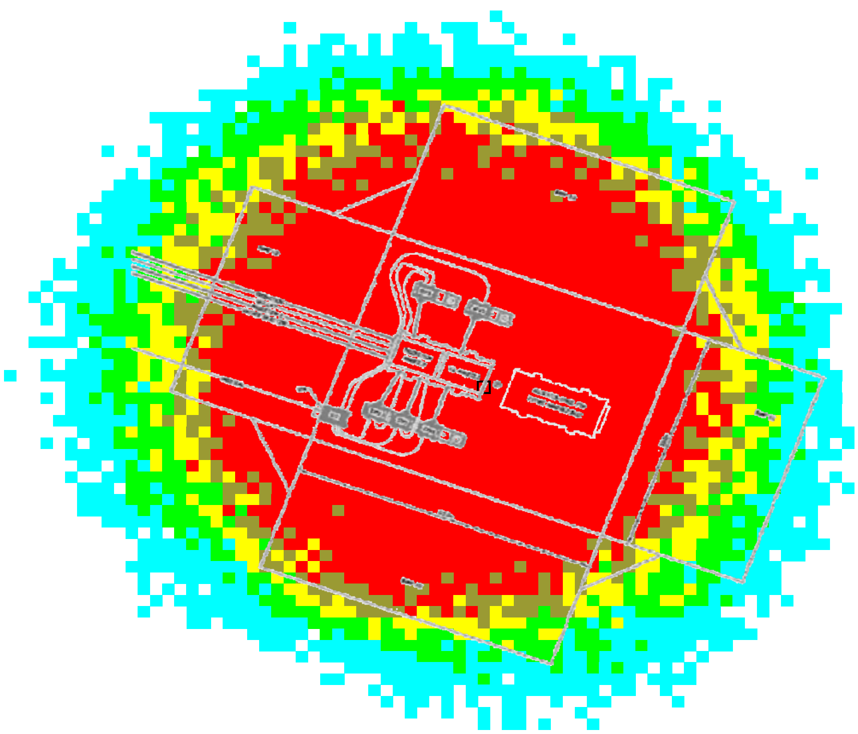

Figure A1: Overall Frequency of Dropped Objects at SWRX

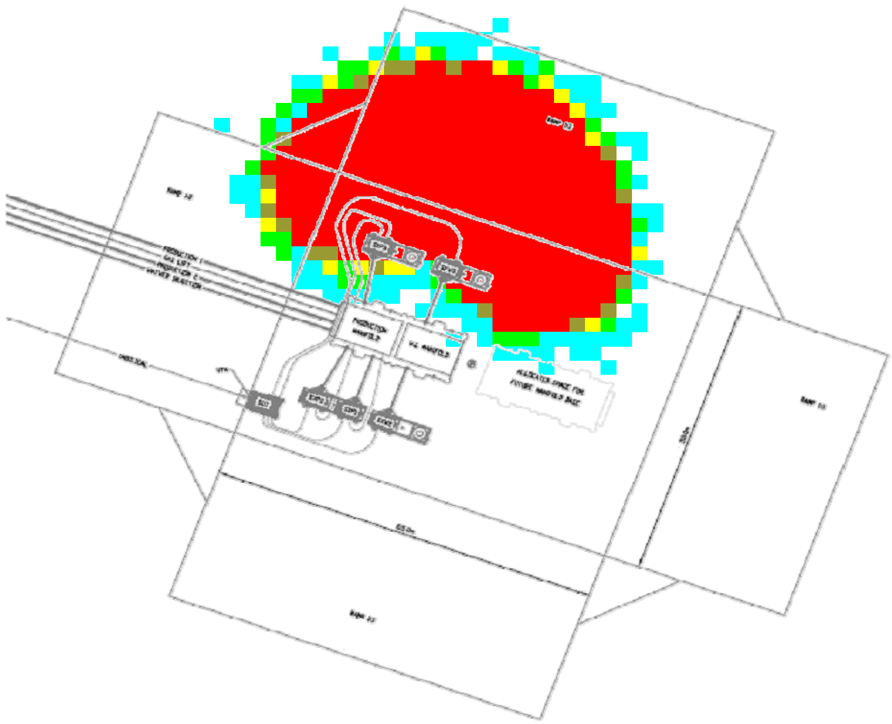

Figure A2: Small Container Lifted by Starboard-side Crane at SWRX

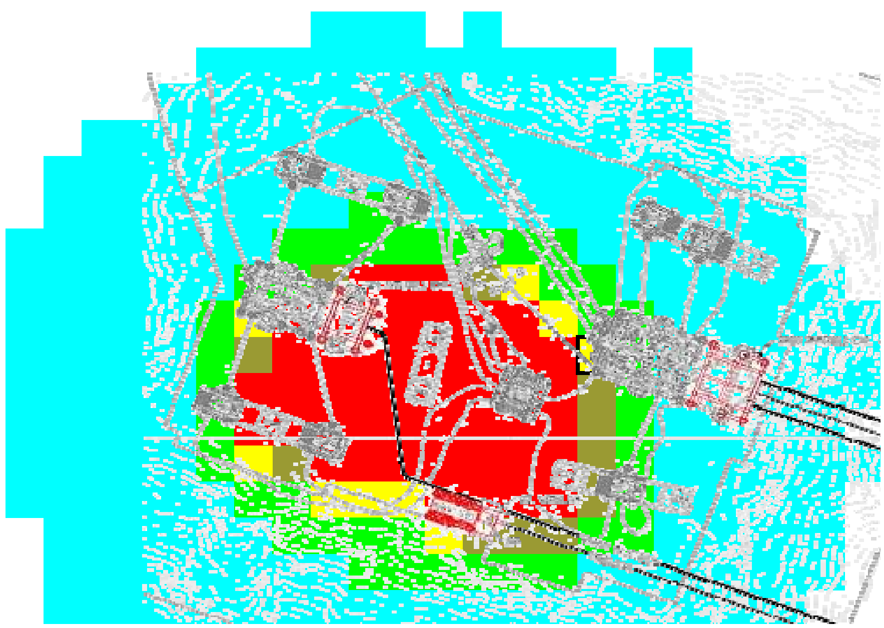

Figure A3: Overall Frequency of Dropped Objects at SGH

APPENDIX B
BLOWOUT CONSEQUENCE ANALYSIS

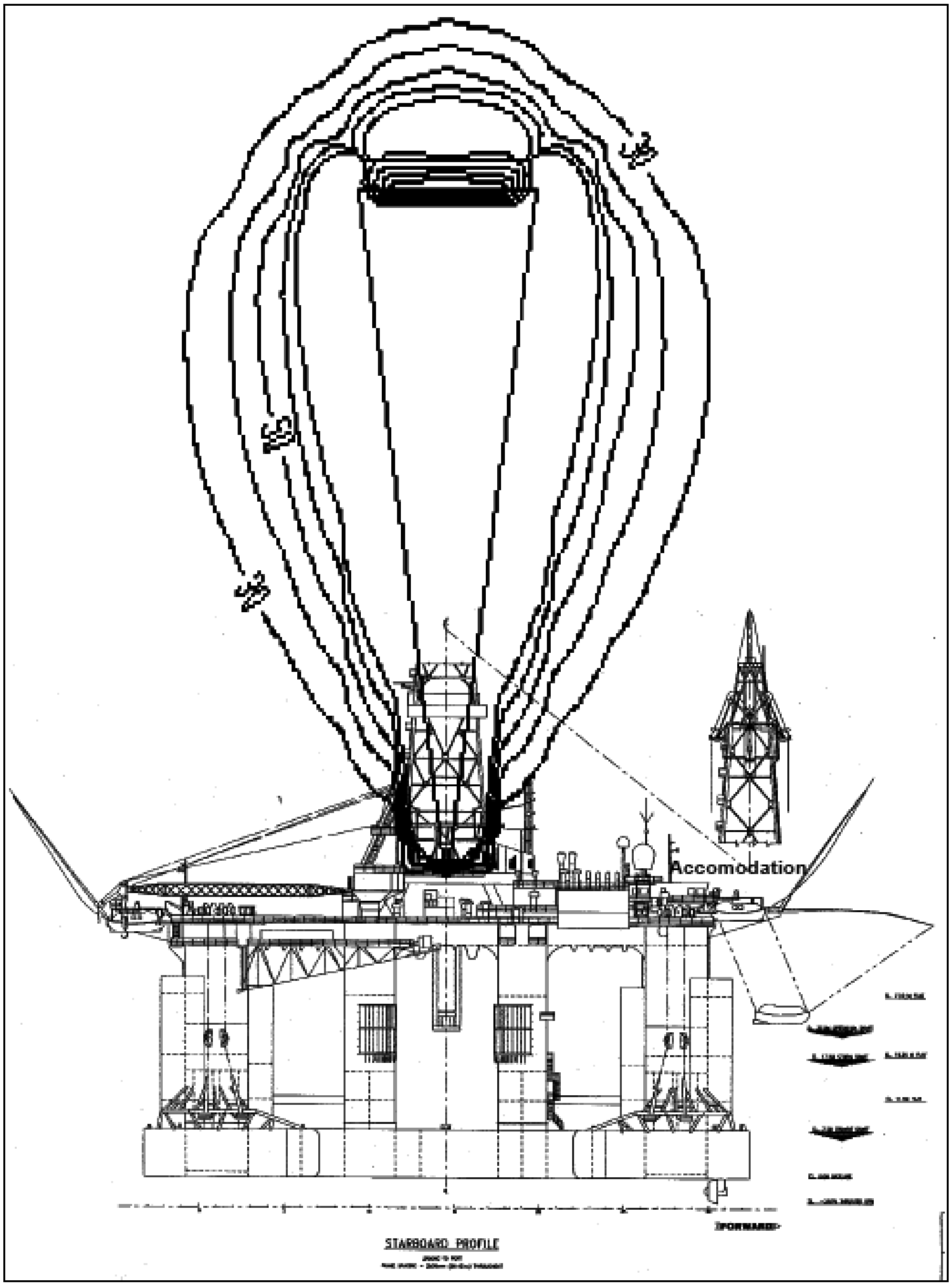

Figure B1: 50kg/s Vertical Drillfloor Blowout with 0m/s Wind (Contours in kW/m^2)

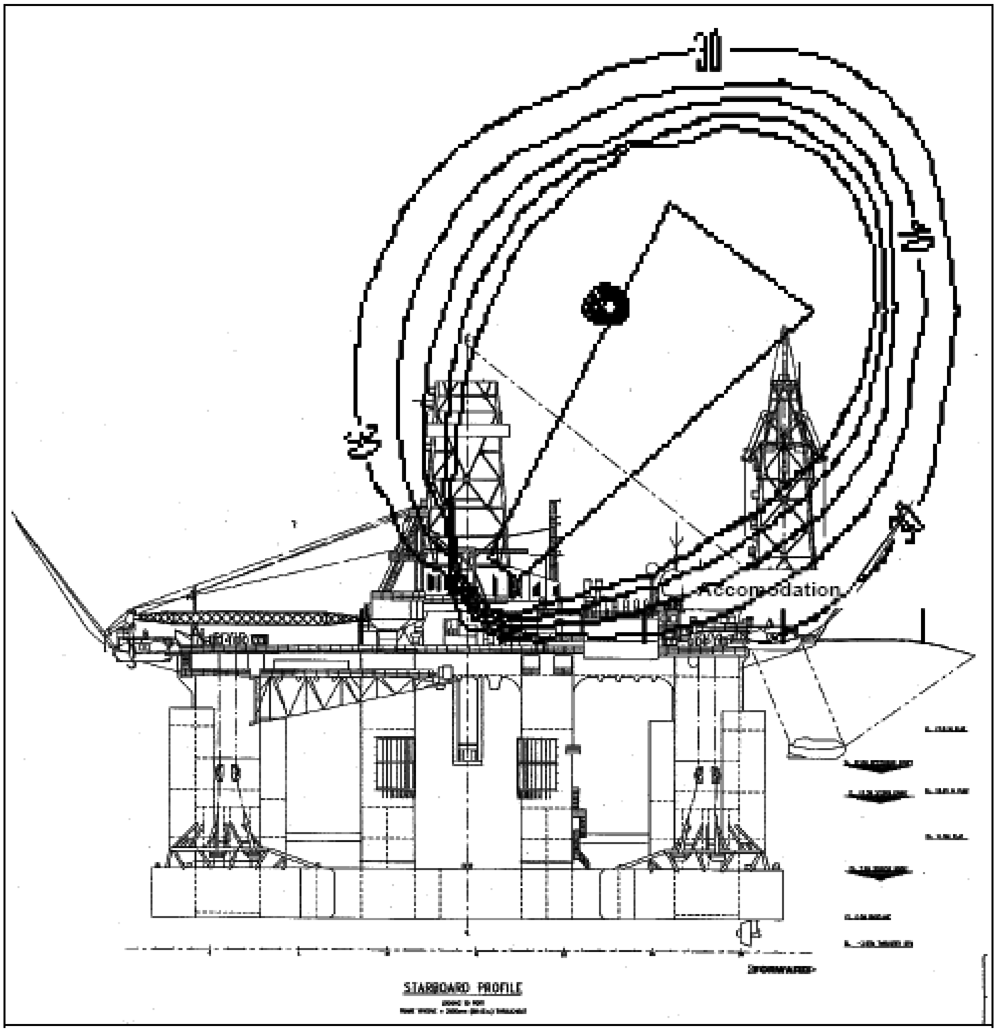

Figure B2: 50kg/s Vertical Drillfloor Blowout with 5m/s Wind Towards Accommodation (Contours in kW/m2)

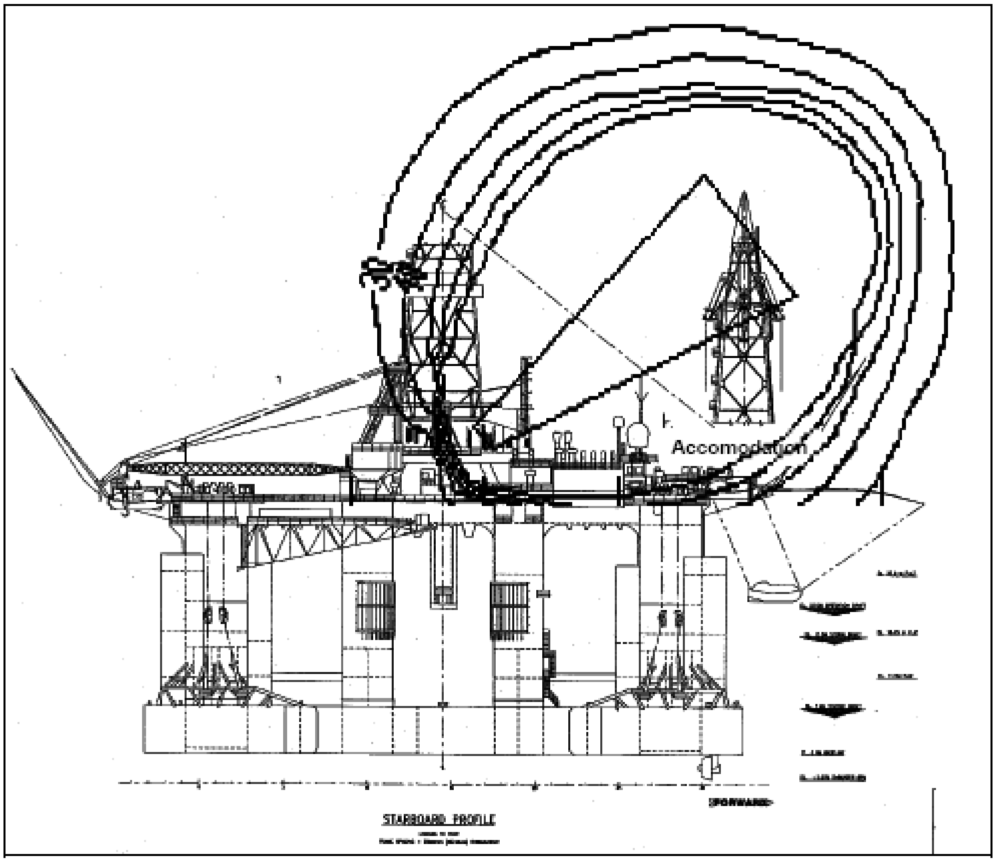

Figure B3: 50kg/s Vertical Drillfloor Blowout with 10m/s Wind Towards Accommodation (Contours in kW/m2)

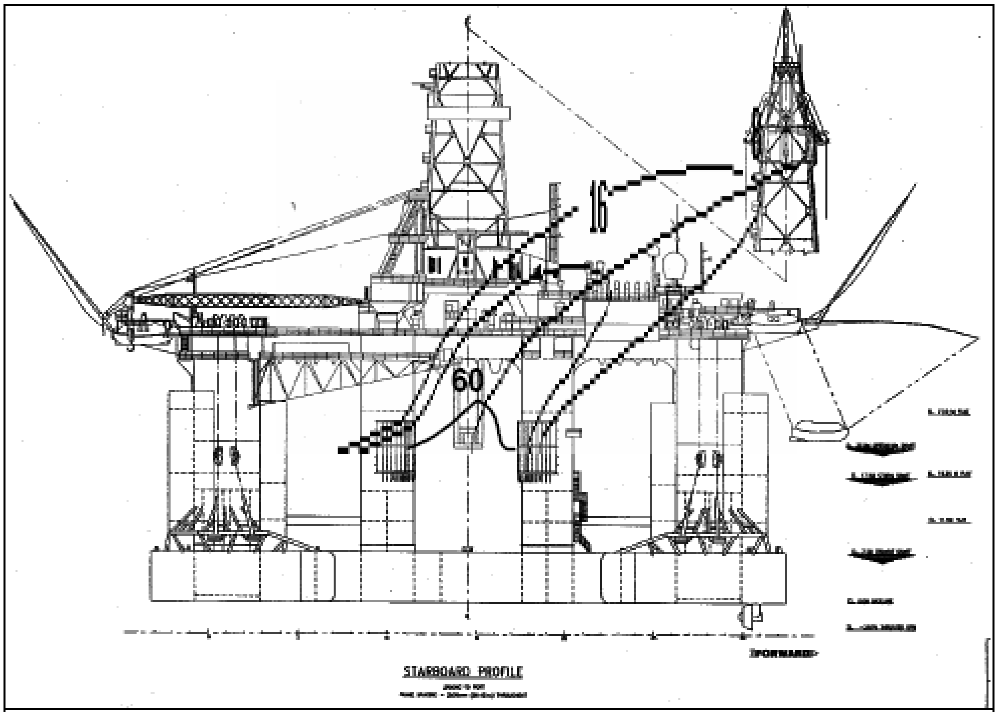

Figure B4: Deep Reservoir Blowout Sea Surface Fire Smoke Dispersion, 5m/s Wind Towards Accommodation, MODU at Operational Draft

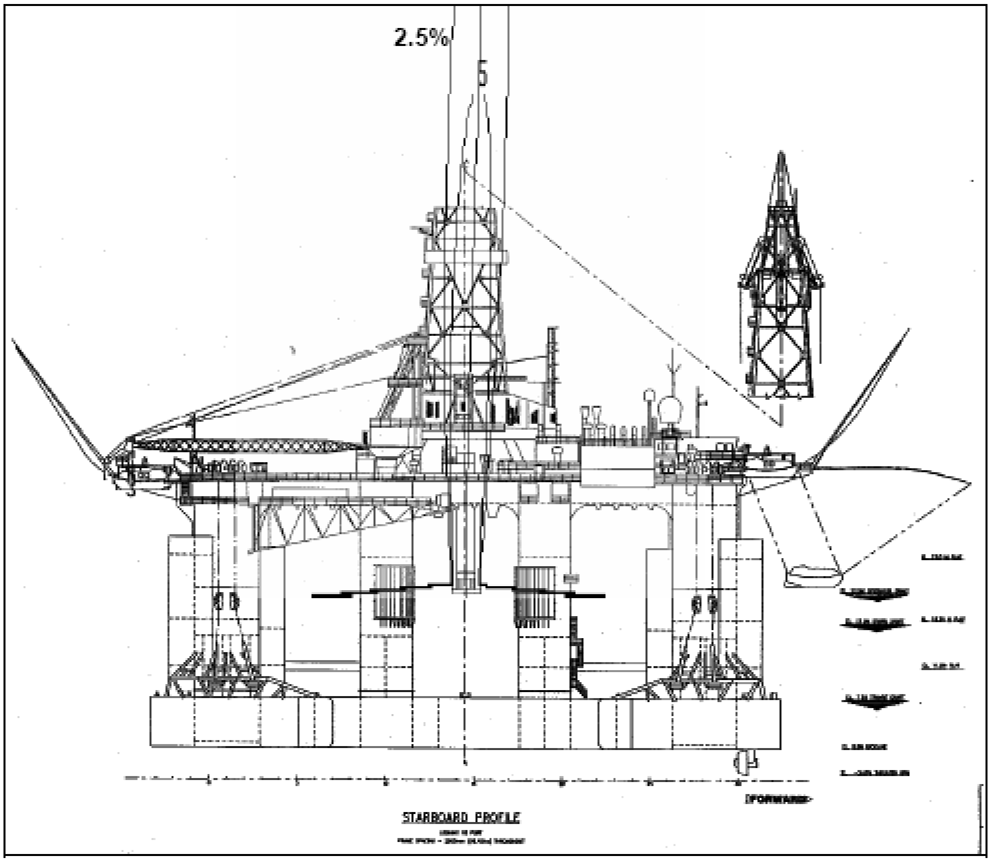

Figure B5: Shallow Gas Blowout Sea Surface Gas Dispersion, 0m/s Wind Towards Accommodation, MODU at Operational Draft

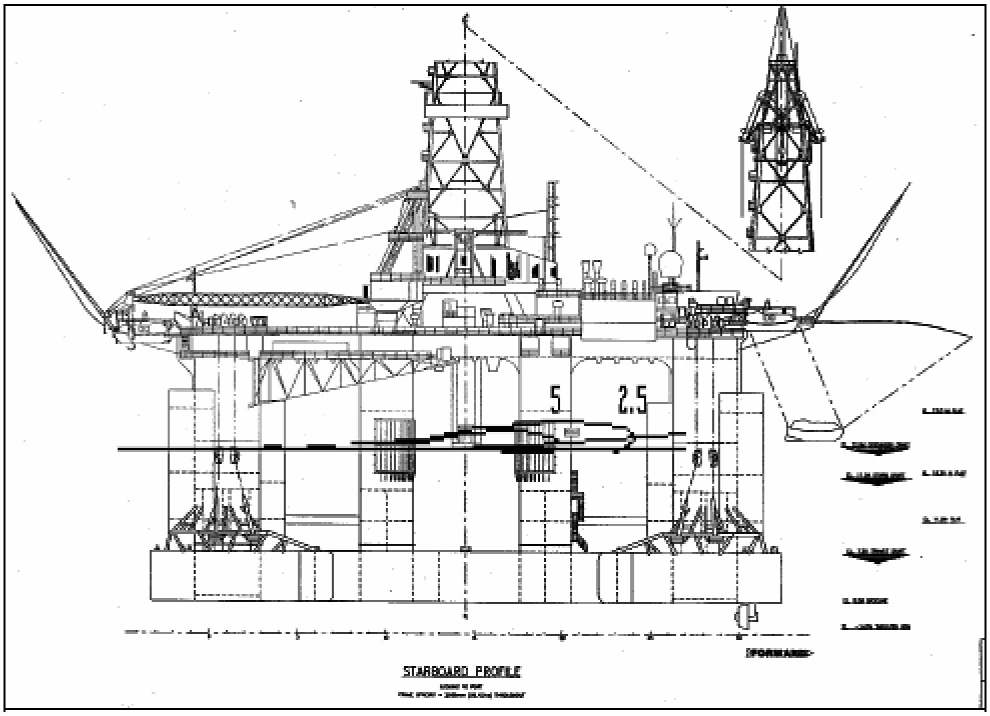

Figure B6: Shallow Gas Blowout Sea Surface Gas Dispersion, 5m/s Wind Towards Accommodation, MODU at Operational Draft

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